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TO THE

# MISCELLANEOUS DOCUMENTS

OF THE

# HOUSE OF REPRESENTATIVES

FOR THE

SECOND SESSION OF THE FORTY-EIGHTH CONGRESS,

1884-'85.

IN SEVENTEEN VOLUMES.

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U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF ENTOMOLOGY.

# INSECTS

AFFECTING THE

# ORANGE.

REPORT ON THE INSECTS AFFECTING THE CULTURE OF THE ORANGE AND OTHER PLANTS OF THE CITRUS FAMILY, WITH PRACTICAL SUGGESTIONS FOR THEIR CONTROL OR EXTERMINATION, MADE, UNDER DIRECTION OF THE ENTOMOLOGIST,

BY

H. G. HUBBARD.

WITH PLATES AND WOOD-CUTS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1885.

JOINT RESOLUTION AUTHORIZING THE PRINTING OF FIVE THOUSAND COPIES OF A SPECIAL REPORT ON INSECTS AFFECTING THE ORANGE TREE.

*Resolved by the House of Representatives (the Senate concurring)*, That there be printed 5,000 copies of a special report from the Department of Agriculture on insects affecting the orange tree, with the necessary illustrations, 2,500 copies of which shall be for the use of the House of Representatives, 1,500 for the use of the Senate, and 1,000 for the use of the Department of Agriculture.

JULY 6, 1882.

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meager, the first part of the work, that relating to Bark-lice, will be found applicable to any region where the Orange is grown, since these universal enemies of the Orange are as cosmopolitan as the plant itself. This part of the work, moreover, includes, in addition to those species which have been the subjects of original investigation in Florida, such notes as have been published upon the Californian species, and which have not as yet made their appearance upon the Orange in the East.

Of the miscellaneous insects considered in the second part of this report, by far the greater number are known only in Florida or Louisiana, and are not likely to make their appearance in the Pacific States.

In a record of observations extending over several years of daily and almost constant work in orange groves, it will not seem strange if many of the facts observed by previous investigators are found repeated in the following pages, and if credit is not always given for priority of discovery in matters relating to the habits of insects, such as may be verified in every orange grove, more intricate researches, or such as have not been reobserved, are always accompanied by the proper references. In this way contributions of interest to orange-growers have been extracted from the writings of well-known entomologists, and particularly from notes and published treatises on orange insects by Glover, Ashmead, and Comstock.

Finally, to your direction and guidance is attributable much of whatever valuable may result from my work; and the influence of your own scientific researches, not less than your personal co-operation, has lightened the labor and made the preparation of this report a pleasant task.

Respectfully submitted,

H. G. HUBBARD,
*Special Agent.*

Prof. C. V. RILEY,
*Entomologist.*

dies back, and finally the older portions of the tree become affected and gradually succumb.

A morbid growth undoubtedly of fungus origin invariably accompanies the disease in its advanced stages. This appears first as discolored patches or slight swellings, which gradually become confluent, and finally burst, forming an eruption of brownish color. The older branches become covered with ridges of exfoliated bark and exudations of gum, presenting an unsightly appearance, not unlike that of "Black-knot" on the plum.

The peculiar microscopic fungus which causes "die-back" is undoubtedly well known to mycologists. The disease yields readily to treatment with dilute carbolic or creosote washes, and is curable by these simple means, provided the exciting cause is removed. This fact may be regarded as confirmatory of its fungus character. The term "die-back" has been applied to several other diseases of the orange, and even to injuries from frost, but the affection above described is the one which is generally known under this name.

The exciting cause of "die-back" has been variously ascribed to over-fertilization, deep planting, imperfect drainage, the presence of humic acid in the soil, and finally to insects. While there is good reason to suppose that conditions of the soil, or of cultivation unfavorable to the growth of the plant, render it liable to the attacks of fungus diseases, there is no evidence that in this case its presence is due to the depredations of insects. It is true that the dead and dying branches of trees affected with die-back attract boring insects of various sorts, but these are found to belong to wood-eating kinds, which act as scavengers merely, and have no connection with the disease itself.

BARK-FUNGUS.—(Plate II, Fig. 2.) Many forms of lichens attach themselves to the trunk of the Orange, in common with other trees, and flourish abundantly in dark and damp situations. There are, however, several mold-like fungi found more exclusively upon the Orange and its allies. These bear a deceptive resemblance to incrustations of Scale-insect.

Of these fungi the one most readily mistaken for Scale-insects commonly appears upon the trunk and branches as little hard excrescences of gray color, which, in wet weather, burst, disclosing a white cottony interior, from which they are often confounded with the "Mealy Bug," (*Dactylopius*). The resemblance to the Coccid is increased when the white spicules, a bundle of which fills each little fungus cup, are beaten out by rains, and felted upon the bark in a mold-like coating. The fungus is confined to the surface of the bark, and appears to germinate exclusively among the *débris* of Scale-insects. It is always found upon trunks that have long been coated with Chaff Scale (*Parlatoria pergandii*). It may also be found upon the leaves when they have become infested with this scale, and is easily removed by gentle friction

between the fingers, coming off with the scales, and showing no close attachment to the surface of the leaf.

The fungus feeds upon the substance of the dead or vacated scales, and is not directly parasitic upon the plant. It is extremely injurious, however, by reason of the closely-felted coating which is formed, causing the bark to harden and the tree to become "hide-bound."

FOOT-ROT.—This disease appears only upon sweet seedling orange trees, most frequently between the ages of nine and twelve years, and often bears a deceptive resemblance to the work of insects. It takes the form of cancerous sores, which destroy the cambium layer of the bark. The sores are confined, except in rare instances, to the foot or collar of the tree, and begin as little cavities filled with fermenting sap and having an offensive, sour odor. These cavities extend their boundaries, the outer bark dries and cracks, allowing the sap to exude and run down upon the outside. Sometimes winding channels are formed in the inner bark by the burrowing of the pus, and when these are laid bare by the knife the resemblance to the track of a "Sawyer," or coleopterous borer, is very striking. When the sores become extensive the dead outer bark above them sloughs away, exposing the dry wood beneath. At this stage the disease is liable to be mistaken for the work of "Wood-lice" or White-ants (Termites), which will, moreover, very likely have made their appearance. The characteristic mark by which the galleries of termites may most readily be distinguished from sores of foot-rot consists of a lining of comminuted wood with which these insects always smooth the walls of their tunnels and chambers. If this is wanting in any of the wounds, even though termites be seen in the immediate vicinity, they cannot be the authors of the mischief.

Foot-rot usually ends by girdling and killing the tree. Like cancer in animals, it is sometimes successfully treated by a free use of the knife, although this frequently serves only to aggravate the difficulty and increase the area of the disease.

Antiseptic treatment with lotions and poultices containing carbolic acid might prove beneficial, but seems never to have been tried. A remedy that has been found practicable, if taken in time, is to plant at the foot of the diseased tree young stocks of the Sour Orange, which is never affected by the disease, and as soon as they have established themselves, to graft them into the trunk two feet or more above the ground. These supplementary stocks will in time replace the original roots and form a new crown, while supporting and preserving the life of the tree.

Many insects, attracted by the fermenting sap, resort to these sores. They are all scavengers, feeding only upon the lifeless bark and sap, or else innocuous and predatory species, such as lurk in dark, cool places everywhere.

SMUT.—A deposit resembling soot is found upon the leaves and bark of trees which have been infested with certain kinds of bark-lice. It is not confined to the Orange, but is found upon the Oleander, the Olive,

and many other plants, and always follows the attacks of Lecanium, Ceroplastes, and other Coccids which produce honey-dew.

The Gall-berry, *Ilex glabra*, a wild plant which grows in great abundance in the sterile "flat woods" of Florida, and which is much infested by Ceroplastes scale, is often blackened by it over many acres in extent.

Prof. W. G. Farlow, in a paper entitled "On a Disease of Olive and Orange Trees occurring in California in the Spring and Summer of 1875," describes and figures this smut, and shows it to be a fungus. He determines it to be *Capnodium citri* Berkeley & Desmazières, a species occurring on Orange, &c., in Europe, and says that it seems nearly or quite identical with the *Fumago salicina* of older writers. (See Tulasne, "Carpologia Fungorum," Pl. XXXIV, Figs. 14 and 20.) In the same paper it is shown, from botanical considerations, that it does not feed on the plant, but on the honey-dew ejected by insects.

Smut upon orange trees has long been known, and its nature and origin have formed the subject of many curious speculations.

In a rare work, published at Nice, in 1806, and entitled "Histoire Naturelle de la Morfée, ou de l'Infection de la Famille des Orangers; par l'Abbé Loquez," this fungus is described, and also the Bark-louse connected with it, and the two are treated as jointly constituting a disease of the Orange, which at that time ravaged the gardens of Italy and southern France.*

Both the fungus and the insect being nourished, according to the author's view, upon the superabundant juices of the plant, he proposes to remedy the disorders produced by their combined attack by depriving the tree of moisture, and by the dessication of its juices.

Smut probably does no more injury than would be occasioned by a similar coating of soot or other fine powder coating the leaves and growing parts of the plant. But as it is never seen except in conjunction with the destructive insects above mentioned, it is not very easy to determine what proportion of the damage is attributable to the fungus alone.

SPLITTING OF FRUIT.—Moore, in his treatise on Orange Culture, says: "The cracking of fruit is occasioned by any suspension of the growth of the fruit, and a consequent hardening of the rind, followed by a sudden flow of sap from any stimulating cause, as highly fertilizing a bearing grove, especially during summer, or a wet spell following a dry." Certain sap-loving beetles of the family *Nitidulidæ*, and also vinegar or pomace flies, attack the split fruit both on the tree and after it has fallen to the ground. The larvæ, which they produce in vast numbers, penetrate the pulp, and cause it to rot with great rapidity.

Many persons, finding the split fruit infested with these grubs and

* The Bark-louse is called by the author *Coccus hesperidum* Linn.; but his minute and excellent account of the insect and its habits clearly indicate that it was a species of Mealy-bug (*Dactylopius*).

maggots, are disposed to consider them the originators of the mischief. A sound orange is, however, most perfectly protected by its oily rind against the attacks of these and most other insects, and it has been found that they die of starvation rather than penetrate it to reach the pulp within.

DROPPING OF FRUIT.—Sucking-bugs (Hemiptera) of several kinds attack the orange, and their punctures invariably cause the fruit to drop and rot.

All fruit trees drop their fruit from causes more or less obscure, but in some way connected with the condition of the plant. The Orange is no exception to this rule, but whenever the loss of fruit is attributable to the bites or punctures of insects, the depredators themselves may be readily discovered, as all are of large size and easily seen.

WINTER-KILLED BRANCHES.—Borers and mining insects are commonly found in dead twigs and branches killed by frost in severe winters. They need occasion no alarm, as they are chiefly scavengers, subsisting upon the dead wood and bark, and seldom do injury to the living parts of the plant.

## THE INSECT FAUNA OF THE ORANGE.

ATTRACTION WHICH THE ORANGE TREE HAS FOR INSECTS.—The dark green and glossy foliage of the orange tree, its dense shade, vigorous growth, and above all the succulence of the young shoots and leaves, render it unusually attractive to insects, not only of leaf-eating kinds, which are general feeders, but also to many predatory and innocuous insects which lurk in cool and shady places or seek protection among sheltering leaves.

Thus many kinds of insects are seen about the trees, some of them injurious, some beneficial, and some occasional visitants, whose presence is without significance for good or ill. In general, it may be said that those which are most visible to the casual observer, and which appear to seek no concealment, are not injurious. They are, as a rule, predatory insects, such as the wasps and sucking-bugs, which prowl about the trees in search of prey, or harmless flies and bees, visiting the flowers for nectar, or sporting among the foliage.

The injurious species generally lie concealed. They hide in folded leaves, excrete a scale, or form a covering of sticks and bark. Many of them are of small size, or, if large, they have some device for their better concealment, and by some peculiarity of form or of coloration they are made to resemble portions of the plant on which they rest, and thus escape observation. The large green "Katydid" readily passes for a leaf, and in spite of its size is very difficult to detect among the foliage. The "Orange Dog," a caterpillar more than 2½ inches long, is so marked with brown and white as to be inconspicuous when resting upon the bark, from its resemblance to a lichen-covered twig. Its

chrysalis presents a still more striking example of the same protective resemblance.

INJURIOUS INSECTS.—First in importance are the Bark-lice (Coccidæ). These sap the life of the tree at its source. The vital juices are sucked up, and probably also poisoned, as the blood of animals sometimes is by the sucking parasites which infest them.

Of insects injuring the root, little is known. As has been shown, "Wood-lice" (Termites) are very often injurious just beneath the surface of the ground, and there are some as yet unknown larvæ which are said to bore into the tap-root at a considerable depth. The trunk has few enemies, except Bark-lice, some species of which prefer to attack that part.

The leaves and twigs, being those portions which offer the greatest extent of exposed surface and the greatest variety of food, support also the largest number of depredating enemies. A large proportion of the leaf eaters feed indiscriminately upon many plants. Such are nearly all the locusts, grasshoppers, and crickets, many caterpillars, and some true bugs which injure by suction. The latter, however, for the most part confine their attentions to the tender shoots, blossom buds and fruit.

With many of these insects the injury is limited to the gnawing of a few leaves, and their importance to the orange-grower is not great. Others, on account of their large size and voracity, defoliate the trees and do appreciable damage.

The tender budding stalks furnish particular species of insects with their especial food; certain other species feed upon the budding leaves in the earlier part of their lives, and, when adult, select them as places of deposit for their eggs. These do especial harm in checking the advancing growth, nipping it in the bud, and inflicting far greater damage than those which confine their attacks to mature parts of the plant.

Injury to the blossom buds and young fruit is caused by certain sucking-bugs (Hemiptera), and the fruit as it approaches maturity is attacked by insects of the same family, whose punctures cause it to drop from the trees and rot.

A minute mite, which appears to be one of the few forms of insect life peculiar to plants of the citrus family, infests the leaves and green fruit, causing upon the rind of the latter a discoloration known as "rust."

BENEFICIAL INSECTS.—Under this head are included a great variety of predaceous insects and parasites, without whose aid in checking the horde of depredators, the cultivation, not only of the Orange, but of most other plants, would be an impossibility.

Every order of insects furnishes its predatory species, which are to a greater or less extent beneficial in destroying the plant-eating kinds upon orange trees. The paper wasps, which hang their nests to the branches, are employed in seeking out spiders and leaf-rolling cater-

pillars, with which to feed their helpless young. The Lady-birds (Coccinellidæ) and their soft-bodied young, with other beetles seen upon the trunk and branches, are busily engaged in the good work of tearing off the scales of Bark-lice and feeding upon the Coccids and their eggs. Wherever is found a tender shoot infested with a colony of Aphides, there, in the midst of the swarming Plant-lice, will be found the slug-like larvæ of predaceous flies (*Syrphus*, etc.), gradually but surely reducing their numbers, in spite of the marvelous powers of reproduction and fecundity of the Plant-lice. Upon the leaves the active young of the Lace-wing (*Chrysopa*) may be seen trundling their little heaps of refuse, beneath which the insect lurks in ambush for its prey. Among the smaller forms, whose operations are invisible to the unassisted eye, are numerous predatory mites, which swarm among the Bark-lice, and greatly aid in holding them in check.

First in importance among beneficial insects, although least in size, and most difficult of observation, are the true parasites, which live within the bodies, and even inhabit the eggs of other insects, and, after having eaten and destroyed their host, issue as minute and active winged insects. Few, if any, of the insect depredators upon the Orange are without internal parasites, belonging with few exceptions to the *Hymenoptera*, an order of four-winged insects of which the bees and wasps are types.

Owing to their small size, and the concealment in which they pass the greater portion of their lives, parasites are themselves seldom seen, but the extent of their operations is sometimes rendered apparent by the great mortality which follows their attacks upon an invading army of plant enemies. Sometimes the presence of a parasite within its body is indicated by a change of form or color which the parasitized insect undergoes before its death, and in any case, after death, the work of the parasite is plainly shown by the round hole which, in issuing, it leaves behind in the body or the protective covering of its host.

INNOCUOUS INSECTS.—Of these little need be said except that their number is legion. Their importance to the agriculturist consists in the liability of their being mistaken for noxious insects, and thus diverting attention from the real depredators.

Many harmless insects, which are so frequently seen upon the orange tree that they may be considered its regular attendants, are to a certain extent beneficial, and either feed upon the various mosses and fungi which accumulate upon the trunk and branches, or upon the lifeless wood and bark of dead portions of the tree.

IMPORTANCE OF DISTINGUISHING FRIENDS FROM FOES.—Although little can be done to increase the efficiency of beneficial insects, much good can at times be accomplished by refraining from interference with their operations. The orange-grower often does injury to his own interests through lack of knowledge in distinguishing friends from foes, and by the indiscriminate killing of all insects which he finds upon his trees.

Horticulturists cannot be expected to acquire a technical knowledge of insects attainable only by specialists, but the entomologist can offer in many cases practical suggestions to aid in protecting the beneficial while accomplishing the destruction of the injurious species. In these pages, wherever our present knowledge permits, the ways and means of securing this advantage will be indicated, and it is hoped, by the aid of plain descriptions and figures, to render recognizable to the orange-grower some of the more important beneficial insects with which he is concerned, as well as the destructive kinds with which he must contend.

PRESENCE OF CERTAIN INJURIOUS INSECTS INDICATED BY ANTS.—Many of the Bark-lice (Coccidæ), as well as the common Plant-louse (Aphis) of the Orange produce sweetish secretions, which are greatly relished by ants; indeed, with some species, the honey-dew ejected by these insects appears to furnish the greater part of their food. At all events, whenever any of these nectar-giving insects exist upon an orange tree, ants will be found in attendance upon them, and a stream of ants ascending and descending the trunk of the tree is an infallible indication of their presence.

The ascending line of ants readily guides the eye to the spot among the twigs and leaves where these enemies lie concealed, and they are especially useful in indicating the whereabouts of incipient colonies, which may thus be destroyed before they have greatly increased, and by their numbers and the extent of their injuries have forced themselves upon our notice.

Young orange trees are particularly liable to suffer injury from Aphis and the soft-bodied, nectar-producing Coccidæ. In the nursery, where the greatest attention should be given to prevent stunting and loss of growth, we may pass rapidly along the rows, and by the presence of ants upon the stocks detect at a glance those plants upon which the pests have obtained a foothold.

## SYSTEMS OF CULTIVATION.

INFLUENCE OF SHADE UPON THE INCREASE OF INSECT PESTS.—Most insects love shade. Some, and among the number Scale-insects, the worst pests of the Orange, prefer the darkness and dampness produced by dense masses of foliage. Plants, on the other hand, require light and air, for want of which the inner branches pine and lose vitality, a condition which also greatly favors the reproduction of Scale-insects.

The good advice of the horticulturist, "Prune back excessive branch growth, give and keep an open head to the tree," may be supplemented and sustained by that of the entomologist, "Let in light and air." Let this not, however, be construed as indorsing the practice of trimming high the trunks, and depriving them of their spreading lower branches,

their best and most natural protection against extremes of heat and cold.

CLEAN CULTURE OR MULCHING PREFERABLE TO CROPPING YOUNG GROVES.—The practice of planting crops between the rows of young orange trees is not without certain evil consequences in attracting depredators. Many of these do indirect damage only. Cotton, for instance, is attacked by the Cotton Worm (*Aletia xylina*) which, after stripping the cotton plants of their leaves, gather upon the orange trees and make their cocoons between the leaves. The orange trees are fouled with their webs and tangles, which foster Scale-insects.

A very appreciable amount of damage is always inflicted by locusts or grasshoppers (Acrididæ) when succulent plants, like Cotton or Cow Pea, are planted in young groves; and when the system of allowing weeds to grow about the trees is pursued, the loss of growth from these insects is sometimes very serious. Older trees do not greatly suffer, and are, moreover, able to spare a portion of their foliage; but very young trees when surrounded by weeds are more or less defoliated and checked in growth. The tops of young trees being small and low their leaders and tender shoots are gnawed and destroyed as fast as they appear, and most of the summer growth may thus be lost.

Objection is sometimes made to mulching orange trees with leaves or vegetable refuse, on the ground that the mulch attracts and harbors insects. Most of the insects which lurk in such places, however, are predaceous species, and may be considered either harmless or beneficial. Very few of them are injurious to the orange tree.

White ants (Termites) must be considered an exception to this rule. They are attracted by decaying vegetable matter, especially by dead wood, and sometimes attack the living tree at or beneath the surface of the ground. To avoid attracting such dangerous neighbors care should be had in mulching to leave the crown of the tree uncovered and exposed to the light and air. It is also best to exclude from the mulch all solid masses of wood material, such as chips and branches.

It is to be noted in regard to the common practice of scattering in the grove and about the trees bits of wood, bark, branches or logs, and allowing them to decay upon the ground, that the danger from this system of fertilizing is not always immediate, but consists rather in attracting termites and inducing them to establish colonies in the vicinity of the trees, which may indeed escape injury while an abundant supply of dead wood remains, but are liable to be attacked if this should become dry or partially exhausted.

SEASONS OF GREATEST INSECT ACTIVITY.—Although in Florida some insects breed continuously throughout the year, there is a very general winter rest from November or December to January or February, according to the severity of the season. The awakening in spring is gradual and not sudden as at the North.

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wards be removed by the Coccid, but firmly anchor it in place. When pulled by force from the bark these long bristles separate and curl up, and the insect is powerless to reinsert them or to again attach itself to the plant, and must inevitably die of starvation.

As soon as the young Bark-louse begins to feed upon the juices of the plant excretions of wax commence to exude from its body. There first appear along the sides and at the end of the body long curled threads of white wax. These form a tangled mass, enveloping the insect; but this first covering is very delicate, and after a time it partially or entirely disappears, owing to the action of the weather. It is succeeded by a covering formed in a similar manner, but of denser texture. This second covering is more persistent; it is in fact the beginning of the permanent scale.

For two or three weeks after the formation of the infantile scale is completed the external appearance of the insect does not change, but within a new body gradually forms and separates from the larva skin until the latter becomes a loosened envelope, from which finally the new-formed insect entirely withdraws its body, passing through a split in the under side. The molted skin is not abandoned, however, but remains, partly covering the Coccid above, and ultimately forms the summit or the extremity of the permanent scale.

With the old larva skin are cast off the now useless members of the larva, and the insect takes the form of a fleshy sack of very simple construction. The joints of the body are indicated by fleshy folds, and the hair-like mouth-tube projects from the under side near one end of the body. The thin outer edge of the last or anal joint of the body is furnished with minute, horny lobes and spines, and its upper and lower surfaces present numerous pores, through which flows a viscid liquid, the material which on hardening forms the protecting scale. On the under side of the last joint can also be plainly seen the vaginal opening, through which pass the eggs or young.

Immediately after molting the body of the Coccid expands, so that it can no longer be entirely covered by the cast skin of the larva, and a portion of the broad terminal joint projects beyond its edge; but the exposed parts are soon flooded with a glutinous fluid, issuing from the pores that stud its surface, and this in a few minutes hardens, and forms an extension of the covering.

During the growth of the insect which follows the molting of the larva skin, the scale covering receives repeated additions of these thin laminæ, each of which underlies and projects slightly beyond the preceding layer, and the scale constantly increases in size and in solidity; while at all times the outer edge remains the thinnest, and therefore the most vulnerable point. Thus the process of growth at this stage is seen to be analogous to that of snails or oysters, which form their shells in an exactly similar manner.

A considerable interval having elapsed after the first molt, the fe-

males again cast their skins; but their form at this time remains unchanged. The second skin like the first remains in place and forms a part of the scale; it is, however, less distinctly visible than the first larval skin, being covered with more or less of the thick excreted material.

Soon after the second molt the females are impregnated by the males. From this time until the scales reach their full size their growth is very rapid. In the linear scales (*Mytilaspis*) the females not only increase in size as their bodies become distended with eggs, but they also shift somewhat their position under the scale, so that finally, at the smaller end, that portion which lies immediately under the molted skins is left vacant. To permit this movement sufficient slack is given the flexible sucking tube between its junction with the body and the point at which it enters the bark.

The eggs are now laid under the scale, beginning at the outer edge. As they are deposited, the body of the female shrinks, and gradually retreats to its former position, leaving the outer portion of the scale filled with eggs. When all her eggs are laid the depleted female shrivels and dries up, and life in her exhausted body gradually becomes extinct.

*The Males.*—As crawling larvæ, and during the time that their scales are forming, the males are indistinguishable from the females; but after the first molt differences begin to appear, and the scales of the males become recognizable by their form or color, although the insects themselves are not markedly different until after the second molt.

Shortly before the second molt of the females the males also cast their skins a second time, and in so doing change to the pupa state. In the pupa, the legs, wings, and other parts of the perfect insect are gradually formed under a mask-like skin, in which the new form is obscurely outlined.

At the second molt the male ejects the skin from its scale, while in the female it remains and forms a part of the scale itself. In the male growth ceases with this molt; but the scale of the female is at this stage less than half its full size; the male scale is therefore much smaller and thinner than that of the other sex, and the first larva skin, but not the second, forms part of its structure.

After remaining a week or sometimes less in the pupa state the pupal envelope is rent and torn from its limbs by the perfect insect. This operation takes place under the scale, and the winged fly leaves its shelter only after a rest of several hours, which, indeed, may be prolonged into days if the weather does not happen to be propitious. The exit of the fly is made by pushing up a portion of the outer edge of the scale. In the elongate scales of Mytilaspis, the escape of the male is facilitated by a thin joint in the scale, which permits the broad end to be lifted as a flap. The body of the male terminates in a spine-shaped organ, by

means of which it is enabled to reach and fertilize the females under their scales.

Prof. J. H. Comstock, whose minute and exhaustive study of the life-histories of certain of our common Scale-insects has left little to be added by subsequent observers, has pointed out that the lives of these insects are divided by their metamorphoses into nearly equal intervals. In the words of this author, "the three intervals between the birth of the female and the first molt, between the latter and the second molt, and between this and the beginning of oviposition are about equal."* The first molt in the male, and also its second molt, or entrance into pupa, take place at nearly the same time with the molts of the female. The existence of the male, however, terminates before the completion of the third interval by the female.

The interval in which the eggs are laid and hatched, and the young larvæ desert the parent scale, is about equal to the preceding intervals. This fourth period completes the cycle of development, and its close witnesses the death of the female, following the departure of her progeny.

During the spring and early summer, in the laboratory at Washington, twenty days appears to have been the mean duration of each interval; in the open air in Florida there is considerable acceleration, due to the warmer climate. This is apparent especially in the later stages of development, which are greatly shortened in summer. The first molt usually takes place within twenty days after hatching, but this first period, although more constant than the following, varies with the season or in different species, from sixteen to twenty-four days. The whole cycle, or brood period in winter, may cover three months, but in summer, it is reduced to five or six weeks.

*Nature of the scale covering.*—As was first clearly pointed out by Prof. C. V. Riley (see Fifth Missouri Entomological Report, p. 80) the scale of the Diaspinæ is a shield-like structure, covering the insect above, and wholly or partially protecting it beneath. It is constructed, as we have seen, in part of the molted skins of the insect, but mainly of a horny excretion, covering or surrounding the latter, and deposited by the Coccid in numerous fine, overlapping layers. The under layer is thinner, and, although perhaps a separate piece, is firmly united to the upper scale at the edges, so that the latter appear to be turned under at the sides. In the long scales the ventral plate consists of a flange along each side, leaving in the middle an open crevice; but in the oval or circular scales it forms an unbroken shield, which entirely separates the body of the insect from contact with the bark.

The scale is permanently fastened upon the tree, and so closely molded to its surface that the pores of the bark or the stomata of the leaf are seen plainly stamped upon it when removed.

The materials of which the scale is constructed are very indestructi-

* Report of Commissioner of Agriculture for 1880, p. 280.

ble, and well serve to protect the helpless organism which they surround, both from the action of the weather and the attacks of external enemies. The molted skins consist of *chitine*, a substance which forms the hard external parts of nearly all insects, and the excreted portion of the scale is composed of a sort of hardened wax, having the toughness of horn.

The upper scale is therefore impervious to most liquids, and is not soluble in acid or alkaline solutions strong enough to injure the plant. It resists the action of oils and of bisulphide of carbon, an almost universal solvent. Many insecticides are therefore inoperative, and all insoluble substances, such as sulphur, etc., are clearly useless, as they do not reach the eggs or mature insects. The thinner, ventral scale is not impervious to the more volatile oils or to alcoholic solutions, some of which reach and kill the insect by penetration through the bark.

As the scale, like the shell of the snail, is formed by successive additions, and keeps pace in its growth with that of the body of the insect within, its vulnerable point is the growing end, and there are times during its formation when the posterior extremity of the insect projects slightly beyond it and becomes exposed to the action of penetrating liquids. This is particularly the case at the critical periods when the Coccid sheds its skin. But when the scale is fully completed and tightly sealed at all points, no insect is more difficult to reach and to destroy.

### *LONG SCALE.*

(*Mytilaspis gloverii*, Packard.)

[Plate III, fig. 2; IV; and Fig. 3.]

*Growth of the Scale.*—In the Long Scale the increase in size takes place chiefly in one direction, producing a linear body, which may be either straight or curved in the form of a cornucopia. The first molt or cast skin of the wandering larva forms its extreme tip, but the delicate film of wax which at first covered this skin disappears, or leaves traces only in the form of two minute projections, and its surface exhibits more or less plainly marked indications of the body-joints of the young louse. Beyond, and partly underlying the shield-shaped first larva skin, is that of the second molt, but this skin is overlaid and imbedded in the substance of the scale, so that its oval outline is faintly visible beneath the coating of horn. The scale increases in width during the first half of its growth, after which the width remains the same and the sides are parallel.

The plate which forms the underside is firmly united to the upper portion of the scale, and projects beyond it on the sides, forming thin flanges, that greatly increase the tenacity of its hold upon the bark. The ventral plate does not entirely cover the under surface, but is divided in the middle, leaving a long, narrow slit, through which the body of the insect comes in contact with the bark.

*The Scale of the Female* is brownish, about 3mm ($\frac{1}{100}$ inch) in length, and less than one-fourth as wide; there is, however, great variation in size, and dwarfed or malformed scales are numerous. When crowded the scales are apt to be warped and curved, although normally they are straight.

*The Scale of the Male* is much smaller than that of the female, quite uniformly 1mm ($\frac{1}{100}$ inch) in length, and very seldom curved.

The colors, varying shades of brown, are lighter, and incline to yellow in the males and young, but become dark mahogany-brown in the older females. The brighter color of the forming scales gives warning of the increase of the pest, and to a practiced eye discloses the age and progress of the brood, even when scattered or mingled with the *débris* of former broods.

In the aggregate, the scales, when densely clustered, have a reddish hue, which has caused this species to be known in some localities as the "Red Scale."

*Female Coccid.*—The body is an elongate, flattened sack, rounded at the extremities and divided into segments or joints. The posterior segment is bordered with spines and plates of microscopic fineness. During the growth of the insect this segment is the widest portion of the body, and upon its surface, as upon a trowel, are laid the successive additions to the scale. After impregnation it loses its prominence, through the swelling of the intermediate joints of the body.

The young and growing females are translucent, waxy white, with the thin outer edge of the last joint yellowish (*chitinous*). As they grow older, they are tinged with amethyst, and toward the end of their lives become dark purple in color.

The adult female is 1.3mm ($\frac{5}{100}$ inch) in length. Its sucking beak considerably exceeds the body in length. The structural details are given in the Report of the Commissioner of Agriculture for 1880, page 323.

*Male Coccid.*—The male is a minute fly, $\frac{1}{100}$ inch in length. Its body is

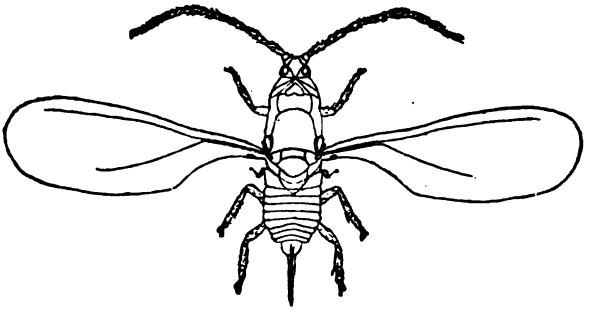

FIG. 3.—*Mytilaspis gloverii* (Pack.), male. (After Comstock.)

pale pink in color, and three or four times as long as wide. The different joints of which it is composed are very closely united, but are indi-

cated upon the naked surface by a variety of lines, some of which inclose shield-shaped plates. Toward the head these plates are small and more or less triangular; upon the middle portion, to which the wings are attached, they are large and with rounded sides. The abdominal extremity is divided into short, transverse joints.

The head is small, and bears upon its apex a pair of rather heavy, many-jointed antennæ, equal to the body in length, and clothed with short hairs. The mouth-organs are wanting, but in their place are seen black dots, which are said to be supplementary eyes. The true eyes are also black in color, and are visible on the sides of the head.

The front pair of legs is placed well forward, and a wide interval separates it from the second and third pairs, which underlie the abdomen. The wings are long, membranous paddles, strengthened by a vein with a single branch, and supported by the aborted hind wings, or balancers, as they are called. The latter are minute, and terminate in a hook which grapples a pocket in the front wing. Although quite large, the wings and also the legs are weak and rather imperfect organs of locomotion, and the insect's powers of flight are not good. The sexual organs, on the other hand, are well developed, and consist externally of a long, stout spine or style at the end of the body.

*Eggs.*—The eggs are elongate-oval. The first laid are white; those laid later are tinged with purple. All become purple before hatching.

*Young Coccid.*—The newly-hatched larva is sometimes white, but usually more or less tinged and mottled with purple. It is oval and flattened, and does not exceed $\frac{1}{100}$ of an inch in length. The body is divided into a number of unequal joints; the first of these constitutes the head, and bears a pair of short antennæ, provided with bristles; minute eyes, widely separated, on each margin, and mouth-organs beneath united to form a sucking beak. The body terminates in two bristles of extreme fineness, which bend downwards, and are dragged after the insect as it walks.

*Life-history.*—The development and formation of the scale in the Diaspinæ has already been described. The history of the Long Scale presents few peculiarities. The newly-hatched larva wanders about for a very short time. As soon as it has settled upon the bark it begins to emit along its sides threads of wax, which in a few days form a white film, and gradually cover the body, beginning from behind and ending in front in two short, horn-like projections. Some of the threads stand out from the rest; being long and curly, they are fragile and easily broken by the wind, but in calm weather they sometimes accumulate, and form cottony tufts or tangles.

This first covering is evanescent, but traces of it remain in the horn-like projections on the sides of the head.

The casting off of the larva skin, or first molt, takes place eighteen or twenty days after birth, and immediately after this the formation of the true scale is begun. The first layers of horn are united to the hinder

end of the larva skin, and partly underlie it. They are thin and transparent, but as each successive layer adds to their thickness, they develop a yellow color, which darkens at length to brown.

In the new form assumed by the insect after the molt the hinder end is broadly dilated, and as this portion of the body forms and determines the width of the scale, the latter for awhile increases in width as it grows in length. After the second molt in the female the extremity of the body ceases to grow in width, and the portion of the scale formed after this molt is linear, *i. e.*, has the sides parallel.

The second molt of the female occurs at the age of six or seven weeks. The male molts and changes to pupa a week or ten days earlier, and as the time required for this transition period is quite short, during the time that the females are casting their skins many of the males complete their transformations and issue from their scales as winged flies.

After the second molt the scale of the female continues to grow, and more than doubles its length, but increases little in width.

In nine or ten weeks from her birth the female begins to deposit eggs. At this time her body, although greatly elongated and distended with ova, does not entirely fill the scale; a space equal to about one-quarter of its entire length is left vacant at the upper or narrow end. The female is able, by means of the serrated edges of her body, to make a slight forward and backward movement within this vacant space.

The eggs are laid in two rows, and are placed obliquely, the eggs of one row alternating and interlocking at the ends with those of the other. The number of eggs laid by a single female varies greatly, but rarely exceeds thirty. The deposition of her eggs occupies the female from one to three weeks, according to the season. The eggs hatch within one week, unless retarded by cold weather. The first laid, those at the outer end, are the first to hatch, but the young lice usually remain several days under the parent scale. The egg-shells are left in place in the scale, but their arrangement is somewhat disturbed by the movements of the latest hatched young in making their escape.

The female after depositing all her eggs is much shrunken, and becomes very dark purple in color. The end of her existence is passed in that portion of the scale which she occupied at the time of the last molt.

*Brood Periods.*—There are at least three and sometimes four generations of Long Scale during the year, but the division into separate broods is not as distinct and clearly defined as with many other insects. The open winters in countries where the Orange is grown permit continuous breeding throughout the year, and at all seasons scales in every stage of development may be found upon the trees.

Not only does the time required by the insect for its development vary greatly in different seasons, and under varying conditions, but also individual insects in each brood undergo their transformations at unequal intervals, some far outstripping the rest and others lagging

behind. This scattering in early broods confuses the succeeding ones and renders it impossible to assign to each an exact season or invariable duration. But although the limits of each brood cannot be exactly defined, the general progress in development may be known at any time by the condition of the majority of the scales.

Thus there are times when the number of migrating young reaches a maximum, and the application of remedies then proves particularly effective.

Three such periods occur: The first in spring, usually in March, but sometimes extending into April; the second in June or July; the third in September or October. During the winter months, if the season is a mild one, there is a fourth, very irregular brood beginning in January and continuing through this and the following month. The spring brood that follows is greatly confused. In cold and rainy winters the hatching process is retarded, and the appearance of the larvæ on the return of warm weather is more nearly simultaneous than in ordinary seasons.

*Parasites.*—Upon closely examining a branch or leaf infested with scales of *Mytilaspis gloverii*, there will always be found a certain number which have through their upper surface a small, round hole. The scales thus perforated are invariably females which have not quite completed their growth. They are empty or occupied by mites or other intruders, and the only trace of the original inhabitant which they contain is its dry, distended skin; this is also pierced with a round hole, placed directly beneath the one in the outer shell.

These are the exit holes of Hymenopterous parasites, the most effective enemies of the Scale-insect, and which, after destroying the maker of the scale, and after completing their own transformations in its room, have eaten their way through its skin and its shell, appearing finally as minute four-winged flies, both male and female.

The female parasite, when seeking to deposit her eggs, probes about the edges of the scale in order to find, if possible, an open crevice through which to insert her slender ovipositor. Failing in this she bores directly through the scale, using her ovipositor as a drill, and in this way inserts within the body of the Coccid a single egg.

The footless grub that hatches from this egg lives within the body of the Scale-insect and gradually consumes it. When nothing is left but the empty skin of its host the little parasite, now swollen to an almost globular form, transforms first to a pupa, and then to the perfect fly, which at last makes its appearance through a hole eaten in the walls that surround it.

Several distinct species of these minute parasites attack the Long Scale. They are about $\frac{3}{100}$ inch in length, with an expanse of wing equal to nearly twice their length. The head is large, with large compound eyes, and three minute simple eyes (*ocelli*) like jewels set upon its vertex. The body is rather short and thick. The wings are transparent and beautifully iridescent; they are strengthened for a portion of

their length by a stout vein, placed very near the margin, and having a short spur or branch at or near the end of the vein. The front wings are broader outwards and rounded at the tips. The hind wings are narrow and more pointed at the ends. The antennæ are elbowed, and clubbed at the ends; they arise from the anterior face of the head, in front of the eyes.

In *Aphelinus fuscipennis* Howard, the general color is yellow, with a black band across the head behind the eyes, and several dusky bands upon the body. The wings are clouded with patches of smoky brown. Length, 0.6$^{mm}$ ($\frac{2}{100}$ inch).

*Aphycus flavus* Howard, is uniformly yellow in color, with clear wings. Length, 1.2$^{mm}$, ($\frac{5}{100}$ inch).

Under the name *Aphelinus aspidioticola*, Mr. Ashmead (Orange Insects, page 7) describes another parasite of the Long Scale, which has a reddish brown or dusky body, yellowish legs, and clear wings. It is $\frac{2}{100}$ inch in length. According to Mr. Howard, this insect is not an *Aphelinus*, but belongs to an unknown genus of another family.

These parasites attack the female Long Scale insect about the time of her impregnation, and their egg is deposited, not simply beneath the scale, or, as some writers have affirmed, among the eggs of the Coccid, but within the body of the Coccid itself. The presence of the parasite within her body destroys the fecundity of the Scale-insect and she finally dies without reproducing her kind.

So effective are the attacks of these internal enemies, that not less than 25 per cent. of the scales are destroyed by them, and at times their numbers increase to such an extent that colonies of Long Scale are reduced almost to extermination.

Observations made at various seasons of the year indicate a greater abundance of the parasites in fall and winter, but they are unfailing attendants upon every brood of the Scale-insect. The result of twenty-five detailed examinations in early spring gives an average of 76 per cent. of the scales destroyed by Hymenopterous parasites. Ten examinations during the summer months give an average of 35 per cent., or one-half that of spring. Fifteen observations in autumn and the beginning of winter give an average of 40 per cent. of scales parasitized.

The activity of these insects is not perceptibly diminished by cool weather, which on the other hand greatly retards the development of the Scale-insect. It is not therefore surprising that three-quarters of the winter brood perish from the attacks of these enemies.

*Geographical Distribution. First appearance in the United States.*—The Long Scale is supposed to have originated in China, and to have spread thence to the orange groves of southern Europe and the United States. According to one authority* it made its appearance in Florida in 1838†

* Brown's "Trees of America," cited by Glover, Rept. Commissioner Patents for 1855, Agriculture, p. 117. See also Report for 1858, p. 266.

† Ashmead (Orange Insects, p. 1) gives the date 1835.

at Mandarin, on the Saint John's River, and was first seen in the grove of Mr. H. B. Robinson, upon trees purchased in New York from a ship from China.

In 1840 it was carried to Saint Augustine on trees obtained at Mandarin, and spread rapidly through the groves of that vicinity. Fifteen years later the same author records the spread of the pest throughout all the groves then existing in the State, and says: "Most of the cultivated orange trees in Florida have also been injured by them, their tops and branches having been generally destroyed. Their roots and stems, it is true, remain alive and annually send forth young shoots, only to share the fate of their predecessors."

The disastrous results of this invasion, which, twenty-five years ago, brought ruin to the orange industry, and seemed likely to end in the extermination of the Orange in this country, were due no doubt to the almost complete absence of parasites at the first advent of the Scale-insect, and for some years after it had obtained a foothold. Glover, writing in 1857 an account of the ravages of this Scale-insect in Florida, notes the complete absence of parasites, although flies belonging to the family of the *Chalcididæ* were found to do efficient service in destroying Bark-lice of other and indigenous species.*

At the present day, although this Scale-insect is everywhere disseminated in the groves of Florida and Louisiana, and likewise infests the wild orange trees, however remote from cultivated plantations, the destructive hordes are held in check by the effective attacks of parasites everywhere accompanying the Bark-lice, and increasing with their increase, so that no general onslaught of the Long Scale at least is likely ever again to occur in this country, and only local irruptions of the pest need be feared.

* Report of Commissioner of Patents for 1858, Agriculture.

# CHAPTER II.

## DIASPINÆ—Continued.

### *PURPLE SCALE.*

### (*Mytilaspis citricola*, Packard.)

[Plate III, Fig. 1, 1*a*, 1*b*, 1*c*.]

*Scale of Female.*—The scale of this species is larger than that of the Long Scale. Large females exceed 3$^{mm}$ ($\frac{1}{100}$ inch) in length. The form is broadly trumpet-shaped, increasing in width behind, sometimes curved, like a cornucopia, but never with the sides parallel. The surface is smooth and even glossy, and the color varies with age from light to dark red-brown and purple. The molted larva skins are very plainly indicated; they are browned by the sun so as to appear scorched.

*Scale of Male.*—The scale of the male is less than half as long as that of the female (1.4$^{mm}$ = $\frac{5}{100}$ inch); it is also more linear in shape, and uniformly dark purple in color. The thin hinge is always indicated by a line of lighter color across the upper surface of the scale, near the outer end.

The purple color of the male scales gives the mass of scales in the aggregate a characteristic hue, which readily distinguishes this species from all others found upon the Orange.

*Female.*—The insect within, as well as its outer covering, has a broader and less linear form than the Long Scale. The two species also differ in the number and structure of the microscopic plates and spines, with which the margins of the last two joints of the body are armed. The number of excreting pores and spinnerets is greater in *M. citricola* than in *M. gloverii*.

Mature females of the Purple Scale are 1.3$^{mm}$ ($\frac{5}{100}$ inch) in length, and occupy less than half the space within their completed scales. The color is white, tinged with yellow at the extremities.

*Male.*—The male and also its pupa are pale amethyst in color. The perfect insect is about 1$^{mm}$ ($\frac{4}{100}$ inch) in length, and, excepting in its somewhat stouter form, hardly differs from the male of the preceding species.

*Egg.*—The eggs are pearly white, never amethystine, 0.2$^{mm}$ ($\frac{8}{1000}$ inch) long, elongate oval, often somewhat distorted in shape by crowding. They are laid usually in four rows, but the eggs at the outer end are

irregularly disposed, and sometimes the whole arrangement is confused. The number laid by a single female greatly exceeds that of the Long Scale; it varies from twenty-five to seventy, with a probable average of forty-five.

*Young Larva.*—The newly-hatched young is irregularly oval in shape, 0.3mm ($\frac{12}{1000}$ inch) in length, and of a transparent white color, with a tinge of yellow at the extremities. The antennæ are stout, six-jointed. The eyes are minute, and of so fiery red a color that they resemble grains of cayenne pepper. The two bristles at the end of the body are almost invisible by reason of their fineness.

*Life history.*—The metamorphoses of this species are exactly paralleled by those of the Long Scale, and are undergone in about the same periods of time. The broods of one species are sometimes in advance and at other times slightly behind those of the other.

*Habitat.*—Like the Long Scale, this species is found upon the twigs and branches, but has a somewhat stronger tendency to overrun the leaves and fruit. It is apt to infest the Lemon, Citron, and those varieties of Orange which have large oil cells (Tangerine, etc.). Although it is most at home upon the Orange and its kind, this scale is not exclusively confined to plants of this family, but is probably a general feeder upon plants of the order *Rosaceæ*, which includes nearly all of our fruit trees.

*Origin and Spread.*—The Purple Scale must be a common pest in most countries where the Orange is grown, for it is very frequently seen upon imported plants and upon foreign fruit in the northern markets. In Florida it is fortunately not as common as the Long Scale. It is, however, more abundant in the northern than in the southern portions of the orange belt. It is frequently associated with the Long Scale, and orange-growers do not readily distinguish the two species.

The introduction of the species into this country probably took place at an early date, but no certain knowledge of its first appearance exists. Mr. Ashmead (Orange Insects, p. 26) and Professor Comstock (Report Commissioner of Agriculture for 1880, p. 323) both give Glover as authority for the statement that this scale was imported into Jacksonville, Fla., in 1855, on some lemons sent from Bermuda, but in the citation given Glover refers to an entirely different scale, less than half the size of *Mytilaspis citricola*, of a different shape and habit, and which from his imperfect description appears to be the Chaff Scale, *Parlatoria pergandii* Comstock.

*Parasites.*—The parasites of *Mytilaspis citricola* and *M. gloverii* are identical, and the mode of attack is in both cases the same.

Descriptions of several species will be found in the Report of the Commissioner of Agriculture for 1880.

### *RED SCALE OF FLORIDA.*

(*Aspidiotus ficus*, Ashmead.)

[Figs. 4 and 5.]

The following account of this species is given in the Report of the Commissioner of Agriculture for 1880, page 296:

"*Scale of Female.*—The scale of the female is circular, with the exuviae nearly central; the position of the first skin is indicated by a nipple-like prominence, which in fresh specimens is white, and is the remains of a mass of cottony excretion, beneath which the first skin is shed. The part of the scale covering the second skin is light reddish-brown; the remainder of the scale is much darker, varying from a dark reddish-brown to black, excepting the thin part of the margin, which is gray. When fully grown the scale measures 2$^{mm}$ (.08 inch) in diameter. In some specimens the part covering the exuviae is depressed, and when the scale is removed from the leaf and viewed under a microscope with transmitted light, the exuviae, which are bright yellow, show through this part, causing it to appear as described by Mr. Ashmead. This scale is represented in Fig. 5, natural size; Fig. 5*a*, enlarged. * * *

"*Egg.*—The eggs are pale yellow.

"*Scale of Male.*—The scale of the male is about one-fourth as large as that of the female; the posterior side is prolonged into a thin flap, which is gray in color; in other respects the scale appears like that of the female. (Fig. 5*b*, enlarged.)

"*Male.*—(Fig. 4.) The male is light orange-yellow in color, with the thoracic band dark brown and the eyes purplish-black. It very closely resembles the males of *A. aurantii*, but differs from that species in being

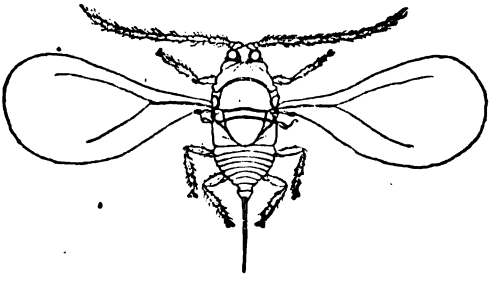

Fig. 4.—*Aspidiotus ficus* (Ashm.), male. (After Comstock.)

a smaller insect, with shorter antennæ, longer style, wider thoracic band, and with the pockets of the wings for the insertion of the hair of the poisers farther from the body.

"*Development of the Insect and formation of the Scale.*—The development of this insect from the egg to the adult state was followed through five generations. I give, however, only the substance of a part of the notes

taken on a single brood—the second one observed—as that will be sufficient for our purpose. The observations were made upon specimens which were colonized on small orange trees in pots in my office in Washington. The rate of the development of the insects was probably slower than would have been the case in the open air in Florida.

"April 12, 1880, specimens of orange leaves infested by this scale were received from Mr. G. W. Holmes, Orlando, Fla. At this date males were found both in the pupa and adult state. The females also varied in size, and some of them were ovipositing. Eggs were placed on an orange tree for special study.

"April 13, the eggs began to hatch. The newly-hatched larva (Fig.

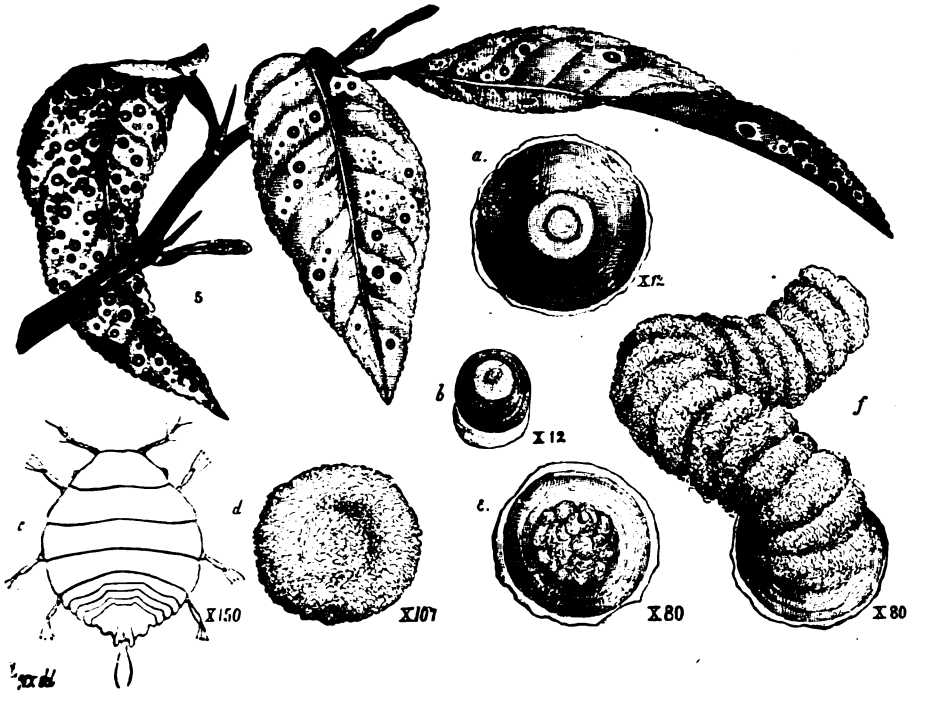


Fig. 5.—*Aspidiotus ficus* (Ashm.). 5, scales on leaves of orange, natural size; *a*, scale of female enlarged; *b*, scale of male, enlarged; *c*, young larva; *d*, *e*, and *f*, different stages in the formation of the scale. (After Comstock.)

5c) is broadly oval in outline and yellow in color. The antennæ are five-jointed; the three basal joints are very short and nearly equal in length; the fourth and fifth joints are each longer than the three basal joints together. The fifth joint is strongly tuberculated at tip so as to appear bifurcated. The eyes are prominent and of the same color as the body. The young larvæ are quite active, but they settle soon after hatching. Some settled the same day that they hatched.

"April 14, it was found that the young lice, although only twenty-four hours old, had formed scales which completely concealed them from

sight. These scales resembled in appearance the fruiting organs of certain minute fungi. They were white, circular, convex, with a slightly depressed ring round the central portion (Fig. 5*d*); their texture was quite dense, and they were not firmly attached to either the insects or the leaf, a slight touch being sufficient to remove them without disturbing the larvæ. The larvæ had not changed in appearance, and were able to move their legs and antennæ.

"April 15, the lice had not changed perceptibly. The scales had become higher and more rounded.

"April 16, the lice had contracted considerably, being now nearly circular, at least as broad as long; in other respects there was no apparent change. The scales were found to vary somewhat; those most advanced having the central portion covered with a loose mass of curled white threads. (Fig. 5*e*.)

"April 17, there was apparent no further change in the larva; but the mass of threads covering the central part of the scale was found in some specimens to have greatly increased in size, equaling in height three or four times the width of the scale. This mass is cottony in appearance, and in those specimens where it is largest is more or less in the form of a plate twisted into a close spiral (Fig. 5*f*).

"April 19, not much change was apparent in the larva, but the mass of cottony excretion upon some of the scales had increased enormously; so that in some cases it extended in a curve from the scale to a point five times the width of the scale above the leaf and down to the leaf.

"April 20, no important change was observed either in the larvæ or scales.

"April 21, it was observed that the larvæ had become more or less transparent, and marked with large irregular yellow spots near the lateral margin of the head and thorax, and with a transverse row of similar spots across the base of the abdomen; the tip of the abdomen is very faintly yellow.

"April 22, no important change was noted.

"April 23, it was observed that the scales appeared faintly reddish in color with the center white; the reddish color, however, was due in part to the body of the larva, which is now orange-red, showing through the scale. It should be noted that in only a part of the specimens did the cottony mass become enlarged as represented in Fig. 5*f*. The greater part of the scales remained until this date of the form shown in Fig. 5*e*, and the cottony spirals have now disappeared, probably having been blown away.

"April 24, some of the larvæ had become deep orange in color.

"April 26, most of the scales had become deep orange in color with the central part white; some had at the center a small nipple-like protuberance; others still preserved a short tuft of a cottony excretion. This tuft is either removed by wind or otherwise, or it becomes com-

pact, melted, as it were, to form the nipple-like projection referred to above.

"April 28, the insects appeared as they did two days ago; the scales had become very tough, and it was with difficulty that they could be removed from the insect.

"April 30, the insects still remained apparently unchanged. Some of the scales were only about one-half as large as others, and still remained perfectly white; these proved to be male scales. All the scales at this date had an elevated ring on the disk with a central nipple.

"May 3, many of the larvæ began to show that they were about to molt, the form of the next stage being visible through the skin of the insect.

"May 5, nearly all of the larvæ had molted; they were now orange-yellow, with the end of the body colorless. The last abdominal segment now presents the excretory pores which are represented in the drawing of the corresponding segment of the adult female. (Fig. 5.)* The molted skin adheres to the inside of the little scale, and therefore cannot be seen from the outside. The scales are now pink, or rose colored, with the center white.

"May 14, the insects had become a somewhat paler yellow, with the anal segment slightly darker. Most of the scales were now dark purple. On removing an insect a very delicate round white plate was observed adhering to the leaf where the mouth parts were inserted.

"May 18, the male scales were fully grown. At this stage they were dark reddish brown in color, with the center white, and the posterior side, which is elongated, gray. At this date some of the males had transformed to pupæ; others were still in the larva state; these larvæ were covered with roundish, more or less confluent yellow spots, leaving only the margin colorless; the end of the body was pale orange. The newly-transformed pupæ resembled in markings the larvæ just described. None of the females had yet molted the second time; their color was deep orange.

"May 21, nearly all of the males had changed to pupæ. It was observed that the last larval skin is pushed backwards from under the scale, to the edge of which it frequently adheres.

"May 24, none of the male pupæ had transformed to the adult state.

"May 29, it was found that during the five days previous more than one-half of the males had issued, and the remainder, though still under the scales, were in the adult state. It was now forty-seven days from the time the larvæ hatched.

"June 2, no males could be found; the females were about one-half grown, and were whitish with irregular yellow spots.

"June 9, eggs were observed within the body of a female.

"June 17, it was found that one of the females had deposited nine eggs, of which six had hatched. This is sixty-six days from the hatching of

* This figure reference is to the original report and not to Fig. 5 of this report.

the egg, and probably about twenty days after impregnation of the female.

"The insects of this brood continued to oviposit until July 1.

"*Number of generations per year.*—This insect, living on orange trees in a room on the north side of a building in Washington, passed through five generations in less than one year; the average time occupied by a single generation was a little less than seventy days. It is probable that in the open air in Orange County, Florida, there are at least six generations each year.

"*Habitat.*—Although I have carefully explored many orange groves in Florida and California, and have had an extensive correspondence with orange-growers, I have been unable to find this species in the last-named State, and have found it only in a single grove in Florida. This is the grove of Messrs. Holmes and Robinson, near Orlando, in Orange County. The insects were first observed here in the spring of 1879 on a sour-orange tree which was brought from Havana, Cuba, in 1874. On learning these facts I sent specimens to a friend at Havana in order to ascertain if the species occurred there. He at once returned me other specimens with the information that it is a very common pest in public gardens of that city.

"This species infests the limbs, leaves, and fruit indiscriminately. In the grove of Messrs. Holmes and Robinson it has spread slowly. The large trees which are infested do not seem to suffer much from it, but the young trees are greatly injured by it. Mr. Holmes considers the disfiguring of the fruit as the worst feature of the pest. The insect has multiplied to such an extent upon the trees upon which I colonized it in my breeding-room, that nearly all of them have been destroyed. The species is certainly one that is greatly to be feared, and there is no doubt that it would be a good investment for the orange-growers of Florida to eradicate the pest, even if in doing so it is found necessary to purchase and destroy all infested trees. This could be done now easily, but if delayed a few years the species will doubtless become permanently established."

Since the publication of the above by Professor Comstock, the Red Scale of Florida has made its appearance at San Mateo upon the St. Johns River. Its transportation was accomplished in 1881 or 1882 by means of infested fruit (Lemons), sent from Orlando, and packed for shipment at San Mateo. From the packing-house the pest escaped to orange trees in the vicinity, and soon obtained a foothold in the surrounding groves.

### *RED SCALE OF CALIFORNIA.*

(*Aspidiotus aurantiæ* Maskell.)

[Fig. 6.]

This very destructive pest of the Orange is known as yet only from California; its introduction into Florida upon imported plants is how-

ever greatly to be feared. The following discussion of the species is found in the Report of the Commissioner of Agriculture for 1880, p. 293:

"*Scale of Female.*—This scale resembles that of *Aspidiotus ficus* in shape, size, and the presence of the nipple-like prominence, which indicates the position of the first larval skin; but it can be readily distinguished from the scale of that species as follows: It is light gray, and quite translucent; its apparent color depending on the color of the insect beneath, and varying from a light greenish yellow to a bright reddish brown; the central third (that part which covers the second skin) is as dark, and usually darker than the remainder of the scale; and when the female is fully grown the peculiar reniform body is discernible through the scale, causing the darker part of the outer two-thirds of the scale to appear as a broken ring. (Fig. 6*b*.) * * *

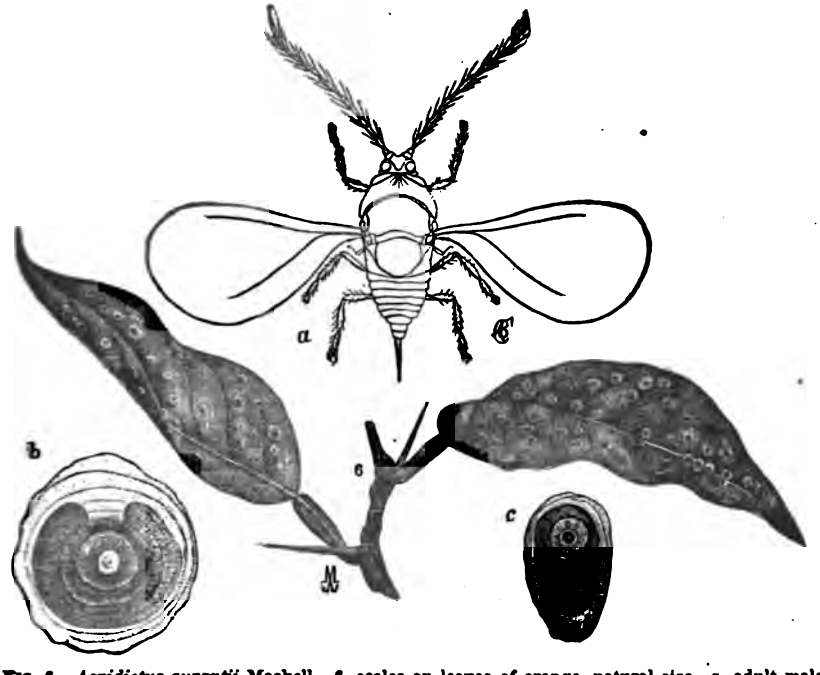


FIG. 6.—*Aspidiotus aurantii* Maskell. 6, scales on leaves of orange, natural size; *a*, adult male, much enlarged; *b*, scales of female, enlarged; *c*, scale of male, enlarged. (After Comstock.)

"*Egg.*—I have not seen the eggs of this species, excepting those taken from the body of the female. And as I have repeatedly found young larvæ under the scales I am led to believe that the species is viviparous.

"*Scale of Male.*—The scale of the male resembles that of the female, excepting that it is only one-fourth as large; the posterior side is prolonged into a flap, which is quite thin; and the part which covers the larval skin is often lighter than the remainder of the scale.

"*Male.*—The male is light yellow, with the thoracic band brown, and

the eyes purplish black. The outline drawing, Fig. 6*a*, represents the shape of the various organs.

"*Habitat.*—I have observed this species in several groves at San Gabriel and Los Angeles, Cal. At the first-named place, where it is very abundant, it is said to have first appeared on a budded orange tree which was purchased by Mr. L. J. Rose, at one of the hot-houses in San Francisco. At Los Angeles it appears to have spread from six lemon trees which were brought from Australia by Don Mateo Keller.

"At first I considered this an undescribed species, as I could find no description of it either in American or European entomological publications. I therefore described it in the Canadian Entomologist under the name of *Aspidiotus citri*. Afterwards I obtained copies of the papers "*On some Coccidæ in New Zealand*," by W. M. Maskell, published in the Transactions and Proceedings of the New Zealand Institute, and found that he had described an insect infesting oranges and lemons imported into New Zealand from Sydney which was either identical with or very closely allied to the red scale of California. I at once sent to Mr. Maskell for specimens of the species described by him. These have just been received and prove to be specifically identical with those infesting citrus trees in California. Thus the question as to source from which we derived this pest is settled beyond a doubt.

"I have found *Aspidiotus aurantii* only on citrus trees. It infests the trunk, limbs, leaves, and fruit. The infested leaves turn yellow, and when badly infested they drop from the tree. This species spreads quite rapidly; and from what I have seen of it, I believe that it is more to be feared than any other scale insect infesting citrus fruits in this country. As illustrating the extent of its ravages in Australia, Dr. Bleasdale told me of a grove of thirty-three acres which nine years ago rented for £1,800 per year, and for which three years ago only £120 rent could be obtained.

"Specimens of this insect colonized on orange trees in the breeding room of the Department passed through their entire existence in a little more than two months; hence it is probable that in the open air in Southern California there are at least five generations each year, and possibly six. The mode of the formation of the scale in this species very closely resembles that of *A. ficus*, described at length in this report. The ventral scale, however, reaches a greater degree of development in *A. aurantii* than in *A. ficus*. At first it consists of a very delicate film upon the leaf; when the second molt occurs it is strengthened by the ventral half of the cast skin, the skin splitting about the margin of the insect, the dorsal half adhering to the dorsal scale and the ventral half to the ventral scale. Later, after the impregnation of the female, the ventral scale becomes firmly attached to the dorsal scale and to the insect; so that it is almost impossible to remove an adult female from her scale."

### *THE WHITE SCALE.*

### (*Aspidiotus nerii* Bouché.)

[Fig. 7.]

Although this species has not yet been reported from orange groves in Florida, it is known to occur upon various plants, within the limits of the State. Professor Comstock, in the Report of the Commissioner of Agriculture for 1880, p. 301, gives the following account of its appearance and habits:

"*Scale of the Female*.—The scale of the female is flat, whitish, or light gray in color, and with the exuviae central or nearly so (Fig. 7*c*). Exuviae dull orange yellow; the first skin usually showing the segmentation distinctly, the second skin more or less covered with secretion, often appearing only as an orange-colored circle surrounding the first skin. Ventral scale a mere film applied to bark of plant. Diameter of fully-formed scale, 2$^{mm}$ (.08 inch). * * *

"*Eggs*.—The eggs are very light yellow in color.

"*Scale of Male*.—The scale of the male is slightly elongated, with the larval skin nearly central; it is snowy white with the larval skin light yellow; longest diameter, 1$^{mm}$ (.04 inch) (Fig. 7 *b*).

"*Male*.—The adult male is yellow, mottled with reddish brown, central part of thoracic band reddish. Other characters represented in Fig. 7*a*.

"*Habitat*.—This is a very common European species which infests many different plants, and it is spread throughout our country from the

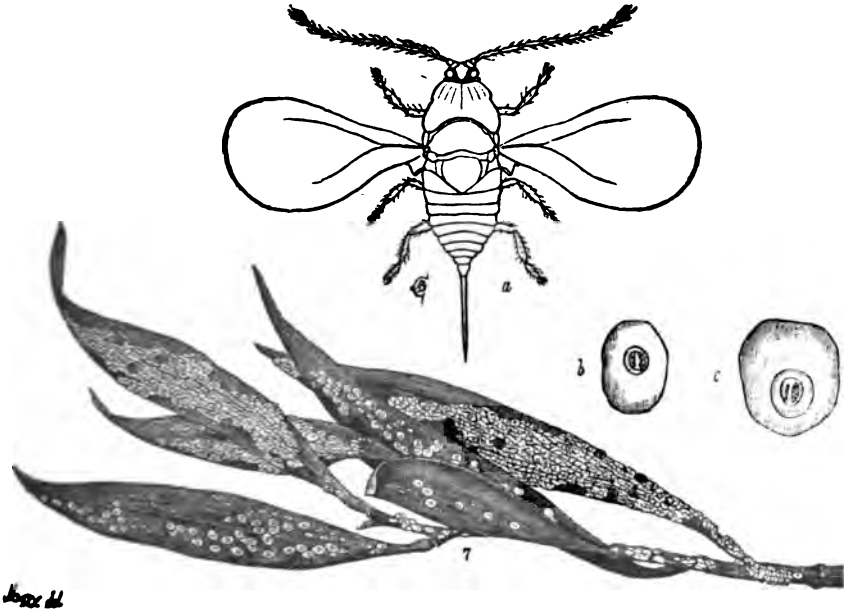


FIG. 7.—*Aspidiotus nerii* Bouché. 7, scales on leaves of acacia, natural size; *a*, adult male, enlarged; *b*, scale of male, enlarged; *c*, scale of female, enlarged. (After Comstock.)

Atlantic to the Pacific, and from the Great Lakes to the Gulf of Mexico. I have found it more abundant on acacias in California than elsewhere,

and for a time believed that it had been introduced from Australia with this tree. Many trees were found the leaves of which were completely covered with the scales, appearing as if they had been coated with whitewash. Leaves of magnolia were received from Mr. C. H. Dwinelle, Berkeley, Cal., which were infested to a similar extent. The following is a list of the plants upon which I have studied this species: Acacia, Magnolia, oleander, maple, Yucca, plum, cherry, currant, and Melia (*Melia azederach*) in California; oleander in Utah; English ivy in a conservatory at Ithaca, N. Y.; ivy and "China tree" from Dr. R. S. Turner, Fort George, Fla.; grass and clover growing in pots with orange trees upon which I was rearing the scale at this Department; lemons imported from the Mediterranean by a San Francisco dealer; and lemons forwarded to me by Mr. Alex. Craw from the grove of Mr. Wolfkill, at Los Angeles, Cal.

"The scales upon magnolia from Berkeley, Cal., and upon oleander from Salt Lake City appear somewhat different from those on acacia and other plants. But after a very careful study of the different forms from each plant, I am unable to point out any character which will distinguish those on magnolia and oleander from others.

"Specimens of infested lemons from Europe were forwarded to me at Washington by the editor of the Riverside Press and Horticulturist, who had received them from a correspondent in San Francisco, who had imported them from the Mediterranean. Notwithstanding the great distance (once across the Atlantic and twice across the continent) which this fruit had been transported, the insects infesting it were alive and in a healthy condition. This illustrates the ease with which these insects may spread from one country to another, and the dangers attending the introduction of foreign fruit and nursery stock.

"The appearance of this pest upon citrus fruits in Southern California is greatly to be regretted, for the species is already so common on other plants that it may be difficult to keep the orange groves free from it. The fact, however, that it infests acacia, oleander, and other plants to such a great extent, and has been observed but few times in this country on citrus fruits, may be taken as an indication that it is not liable to multiply to any great extent upon oranges and lemons.

"In the specimens which I have seen the leaves of the lemon were not infested, but the scales were very abundant on the fruit.

"The young of this insect which were found on ivy in Florida were colonized on an orange tree in the breeding-room of the Department. When one day old the larvæ had settled and commenced excreting a covering; when four days old this covering was quite dense; on the twentieth day some larvæ molted, and on the twenty-eighth day the second molt occurred. It was observed that this molt was accomplished by a splitting of the skin at the sides of the body, so that the dorsal half of the skin became attached to the scale and the ventral half to the leaf. Soon after this molt all the specimens died. This was an indication that this species could not mature upon the orange. But a very

careful study of the form from Florida has failed to reveal any character by which it can be separated from that living on lemon in California.

"Although I failed to ascertain the time occupied by a single generation, the following notes indicate that there are at least two each year, and probably more. On the 13th of April, 1880, specimens of magnolia leaves were received from Berkeley, Cal., infested by this insect. The eggs were hatching from this date till 27th April. During this time (22d April) leaves of ivy were received from Florida, upon which were scales and newly-hatched young of this species. On the 21st of May other specimens were received from Florida; of these the females were about one half grown, and the males were in the pupa state.

"On the 24th of August I observed again at Los Angeles, Cal., the eggs of this species.

"During April adult males emerged in my breeding-cages from both the California (Berkeley) and Florida specimens. And during August the males were again flying at Los Angeles, Cal.

"In conservatories there is apparently no regularity in the periods of this insect; for specimens of all stages, from the egg to the adult, may be observed at the same time."

### *CHAFF SCALE.*

(*Parlatoria pergandii* Comstock.)

[Plate V, and Figs. 8 and 9.]

*Scale of Female.*—This is a thin, light colored scale, less than half as long as either of the Mytilaspis scales. It is more or less circular, usually somewhat pointed, and less curved upon one side than upon the other. The first larval skin is a little darker in color than the rest of the scale; it is distinct, and forms a circular shield, placed near the edge and on the side opposite the point. Beyond and partly underneath the first larval skin may be distinguished the larger but less distinctly visible shield of the second molt. In well developed scales several faintly elevated lines or ridges are marked upon the upper surface, which radiate from the point of beginning of the scale, and are partly obliterated where they are covered by the molted skins. A structure somewhat similar to this of the Chaff Scale is seen in many sea shells, such as the limpet and the oyster.

FIG. 8.—*Parlatoria pergandii* Comst. *a*, scale of female, enlarged; *b*, scale of male, enlarged. (After Comstock.)

The female scale is light straw color, 1.4$^{mm}$ to 1.6$^{mm}$ (0.06 inch) long.

*Scale of Male.*—The male scale is slender and of nearly equal width throughout. The material of which it is composed is very thin and white in color; the larva skin at one end covers about one-third of the surface, is darker than the rest of the scale, and has a greenish tinge, or a dark green center. Length, 1$^{mm}$ (0.04 inch).

*Female.*—The female has the form of a thickened disk, nearly circular in outline. The edges of the last four or five joints are serrate, with minute tooth-like lobes and plates. The color, at first waxy white,

becomes dark purple at maturity. The serrated hind margin is thin and tinged with yellow.

The mature females do not entirely fill their scales. When gravid with eggs, their bodies, although much thickened, are reduced in circumference, and in laying they surround themselves with a nearly complete circle of eggs. Length of mature female 0.6mm (0.02 inch).

*Eggs.*—The eggs are as large or larger than those of the Long Scale, and resemble them in shape and color. They are nearly 0.2mm (0.008 inch) in length, and are more or less amethystine in color.

*Young Larva.*—The migrating larva is very broadly oval, and mottled with purple. It differs from the larva of related species only in minute details.

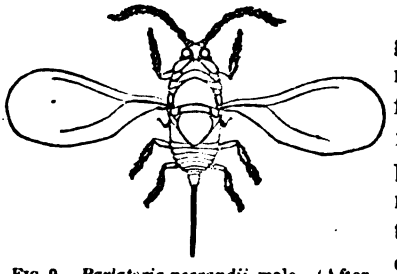

FIG. 9.—*Parlatoria pergandii*, male. (After Comstock.)

*Male.* (Fig. 9.)—As soon as it begins to form its permanent scale, the male insect becomes distinguishable from the female by its more elongate form, and it soon turns to a dark purple-red color. The skin of the second molt is pushed toward the mouth or thrown out of the scale. After shedding this skin the male insect becomes a pupa of dark red or purple color, and has the form of the fly with members folded or abbreviated.

The perfect insect emerges from the thin outer end of its scale, which, however, has no hinge or flap. The fly is very similar to those of the genus *Aspidiotus*, but is shorter and stouter, and has larger eyes than the species of *Mytilaspis*. The color is purple, mottled, and somewhat paler upon the large shield of the upper surface. Length to the tip of the stylet about equal to that of its scale, 0.6mm (0.02 inch).

*Life-history.*—The young Chaff Scale repeats with slight variations the history of the species already mentioned. After wandering a few hours, it chooses a fixed position, very often underneath a pile of old, dead scales, and in a few days covers itself with a circular shield of white tissue, so thin as to be quite transparent. This covering disappears before the time of the first molt. After the molt the females construct a circular and the males a linear scale.

The number of eggs laid is variable. Professor Comstock records in one instance twenty-seven eggs. The average number is sixteen.

*Number of Generations.*—The earlier metamorphoses take place at about the usual intervals of twenty days, but the later periods vary with the seasons, and are greatly accelerated by hot weather.

The Chaff Scale appears to have one more brood than the Long Scale. There are four summer generations, but these broods are so greatly confused by unequal development in the females that the limits of each cannot be exactly defined. The first brood in spring and the last brood

in fall may be assumed to be approximately contemporaneous with those of the Long Scale. They occur in March or April and in September or October. These months are therefore the proper ones for treatment with remedies.

*Habitat.*—The Chaff Scale infests by preference the trunk and larger branches, and to these it generally confines itself until every portion of their surface is thickly coated, and the young Bark-lice can no longer find places to plant themselves. It is also frequently seen upon the fruit, occupying the pit-like depressions of the rind. This habit, combined with its light color, renders it inconspicuous upon the fruit. Upon the trunks of trees, also, its resemblance to the bark causes it to escape notice, so that many persons whose groves are suffering from the attacks of this scale are unaware of its presence.

*Food-plants and Origin.*—It has been found upon various plants growing near infested orange trees. Japonicas and similar thick-leaved plants sometimes suffer severely from its attacks. It is not known to infest any native wild plants, and is not found upon the Wild Orange, except in the immediate vicinity of cultivated plantations. It cannot, therefore, be considered a native insect, nor is anything known with certainty concerning its introduction.

Professor Glover, in his report to the Commissioner of Patents for the year 1855, mentions the introduction in that year of a Scale-insect, which he says was imported into Jacksonville, Fla., on some lemons sent from Bermuda. This Scale-insect has been stated to be *Mytilaspis citricola*. From the brief description given by Glover, it is not possible to determine with certainty the species referred to, but the small size and shape of the female and the white color of the male scales agree closely with the species now under consideration, and render it probable that the Chaff Scale, and not the Purple Scale, was the insect in question.

*Parasites.*—In addition to many external enemies, a single Hymenopterous parasite attacks this scale, and is a very efficient destroyer of the species. It is a larger insect than those found in the scales of Mytilaspis, and its larva does not live within the body of the Coccid, as is usual with these minute parasites, but originates from an egg deposited beneath the scale and among the eggs of the Scale-insect, which is always of adult size when attacked. The grub of the parasite makes room for itself as it grows by eating first the eggs of its host and then her body. Sometimes, indeed, the eggs alone of the Coccid appear to suffice for its support and the mother Bark-louse is not molested.

The pupa of the parasite is formed under the scale, and although without cocoon or coverings of its own, is surrounded by the dry skin and egg-shells of the Bark-louse.

The fly issues through a round hole which it eats in the top of the scale.

The perfect insect is a four-winged fly, 1.2mm (0.05 inch) long, honey-yellow in color, and with dark brown eyes. The antennæ have apparently six joints, but the last three joints are closely united into an elongate club, and the real number of joints is therefore eight. The abdomen is rather broadly oval, and in the female bears on the middle of her under side the sharply-pointed egg-drill.

The larva is a yellowish-white, naked grub, so thick and short as to be almost spherical. It is without visible members, even the head being withdrawn out of sight into the body. The body is plainly ringed, indicating the joints, and the dark intestinal contents are seen as a red or brown cloud through its walls. Length 0.5mm (0.02 inch).

The pupa is twice as long as wide, flattened, oval, and has a tinge of yellow color. It shows the form of the perfect insect through the transparent envelope.*

### *THE ORANGE CHIONASPIS.*

(*Chionaspis citri* Comstock.)

A new Bark-louse of the Orange has been described by Professor Comstock, in the Second Entomological Report of Cornell University, as follows: "In the Report of the Department of Agriculture for 1880 I described a species of Chionaspis which differed from all other species of that genus known at that time by the color of the scale of the female, which is black. This species was found on *Euonymus latifolia* at Norfolk, Va. I stated in my account of this insect that it occurred also on orange trees in Louisiana and Cuba. A re-examination of the specimens on orange has convinced me that they are specifically distinct from those on euonymus. I therefore propose for that form the specific name of *citri*. The species can be recognized by the following characters:

"*Scale of Female.*—The scale of the female is of a dirty blackish brown color with a gray margin; the exuviae are brownish yellow. There is a central ridge from which the sides of the scale slope like the roof of a house. The greater prominence of this ridge, and the more elongated form of the scale are the principal differences between this scale and that of the female of *Ch. euonymi*. There is no danger of its being mistaken for any other known species.

"*Female.*— * * * This species may readily be distinguished from *Ch. euonymi* by the following characters: There are no groups of spinnerets; the mesal lobes are larger and more distinctly serrate than in *Ch. euonymi;* and in the last-named species the plates are in twos, while in *Ch. citri* they occur singly."

According to observations made by Mr. L. O. Howard, the Orange Chionaspis is the especial pest of orange groves in Louisiana. It has been found by him at Pattersonville, Saint Mary's Parish; at Woodville, 50

* This parasite is evidently an *Aphelinus*, but the only specimen in Mr. Hubbard's collection is too poor for specific determination.—C. V. R.

miles below New Orleans; on the Mississippi River above Algiers, and on the east side of the river in the New Orleans cemeteries.

FIG. 10.— *Chionaspis euonymi* Comstock. 10, scales on Euonymus, natural size; *a*, scale of male, enlarged; *b*, scale of female, enlarged. (After Comstock.)

Fig. 10 represents *Chionaspis euonymi* Comstock, to which the above species is very closely allied.

# CHAPTER III.

## DIASPINÆ—Continued.

### RAVAGES OF THE ARMORED SCALES.

*Bark-lice omnipresent in Orange Groves.*—In the foregoing pages an account has been given of all the species of Diaspinæ known to attack citrus plants in this country. The appearance, distinguishing characters and habits of each have been set forth with sufficient clearness, it is hoped, to render recognizable by orange-growers the different members of this group of insect pests, the most destructive and formidable with which they have to contend. It remains to consider the nature and extent of the injuries they inflict and the conditions under which the plant becomes liable to attack.

It may be premised that in all countries where the Orange is extensively cultivated Scale-insects exist, and not seldom make their presence known through the losses they occasion the fruit grower. From time to time there may be sudden irruptions of Scale-insects, which, like an epidemic, are wide-spread in their effects, and overrun a great extent of territory. Such an invasion, as has already been shown, occurred in Florida upon the supposed introduction of the Long Scale. In southern Europe also, where the Orange and the Lemon have been cultivated for centuries, the occurrences of scale epidemics have been recorded, one of which, in the first decade of the present century, prevailed throughout the entire district along the shores of the Mediterranean, from Italy to Spain, and spread consternation among the inhabitants, who were dependent upon the produce of their lemon and orange groves for support.

At the present day, however, owing to a better knowledge of these pests, the use of cheap and effective insecticides, and of effective instruments for applying them, such wide-spread devastation by Scale-insects need not be feared. The omnipresence of the pest, however, compels the orange-grower to be ever upon the alert if he would avoid loss of growth in the young or of productiveness in the older trees.

In Florida the greater part of these losses are caused by three Diaspinous scales: *Mytilaspis gloverii*, the Long Scale; *Mytilaspis citricola*, the Purple Scale, and *Parlatoria pergandii*, the Chaff Scale. These three insects are so universally distributed that it is safe to say no bearing orange tree exists in southern and eastern Florida upon which one or the other cannot be found.

The Long Scale is the most destructive, while it is the most readily destroyed. Few if any localities in the State are free from its presence.

The Purple Scale, being stouter and thicker than the Long Scale, is more difficult to kill. It is not less injurious to the trees which it infests, but is less widely distributed.

The Chaff Scale is hardly less common than the Long Scale, and is very frequently associated with it. Of the three it is decidedly the most difficult to exterminate, owing, in part at least, to its habit of piling or lapping one over the other. Except upon very young trees it seldom does permanent injury, and is much less to be feared than the other two species. Its thinner scale renders it liable to the attacks of enemies to a greater extent than the Mytilaspis scales, and they sometimes cause its complete disappearance from a tree.

A fourth scale of this group, *Aspidiotus ficus* Ashm. has been mentioned as recently introduced, and there are still others awaiting importation from California and elsewhere.

*Agencies which assist their Distribution.*—During the migratory age the restless habit of the young Bark-lice impels them to crawl actively about, turning aside for no obstacles, but mounting every object met with in their path. The instinct of self-protection being entirely wanting in these degraded creatures, they make no distinction between dead and living objects, and crawl without hesitation upon the bodies of other and larger insects. The latter, impelled by the annoying presence of the intruders, fly away, bearing with them the scale larvæ, and thus assist in distributing them upon surrounding plants.

Some insects, however, do not notice, or at least do not resent, the liberties taken by the crawling lice.

Thus the Lady-bird beetles (Coccinellidæ) are frequently seen quietly feeding while several young Bark-lice, evidently attracted by their shining backs, are coursing in all directions over their bodies. It cannot be doubted that even these enemies of the Scale-insect bear with them in their flights this seed of the destroyer and scatter the pest from tree to tree. Doubtless very many flying insects, and also birds, with their sweeping tail-feathers, aid in disseminating Scale-insects.

But spiders, more than any other animals, must be considered efficient instruments in this mischievous work. Not only do they transport the lice—and it is an observed fact that the movements of the latter upon their hairy backs do not incommode the spiders—but they also harbor them under their webs in folded leaves, etc., where, safe from the attacks of parasites and enemies, they increase and multiply inordinately.

The nest web of a spider will most frequently be found the starting point from which the lice swarm forth as from a hive and cover the surrounding parts. Other webs, at a distance from the infected one, will be occupied in time, but only as the tide of scales reaches their vicinity, for it is not the habit of the migrating Bark-lice to wander far

in search of such lurking places, however readily they accept the protection when found.

The observed fact that Scale-insects spread most rapidly in the direction of prevailing winds has often been verified, and has led to the belief in direct transportation by the winds, as the most important agency in their dissemination. This popular theory is thus stated by a writer: "Now, in the spring and fall, just when the insects are hatching and most numerous, we have our heaviest storms. * * * During one of these storms I have often seen leaves, twigs, and sometimes whole branches taken up and carried whirling through the air for a quarter of a mile or further. How easy, then, would it be for these microscopical insects, but a few atoms in weight, to be carried for miles."*

The gentle southeast trade-winds of Florida and the storms which are occasional, and, fortunately, somewhat rare visitants, are very different phenomena. While the influence of the former is sometimes seen in the more rapid spread of the Scale-insects towards the northwest, it has never been observed that a sudden extension of the pest has followed any of the violent or long-continued wind storms on record.

That tempest-borne branches and leaves might carry the infection to a distance cannot of course be denied, but the dissemination of Scale-insects, continues without interruption at all seasons and in all parts of the State, a process of such constancy and regularity, cannot be attributed in any great measure to the fitful agency of occasional storms.

Nor can it be by direct transportation that the trade-winds assist in spreading Scale-insects, for winds of moderate force are not competent to dislodge the young lice from the plants. Of this any one may be convinced by trial with a bellows or with the breath. Minute and insignificant in weight though they are, they cling with tenacity to the bark, and the pressure of air upon their thin bodies only serves to press them into closer contact with the surface.

It is rather to the indirect action of the wind, to the influence which it exerts upon the flight of insects and other winged animals which transport Scale-insects, that we must look for an explanation of the observed phenomena.

And particularly is this influence of the wind felt in the case of spiders, most of the species of which are dependent upon the wind in their migrations. For, although wingless, they are enabled by means of the buoyancy of their web and the power which they possess of reeling it out upon the wind to bridge long gaps from tree to tree, and even to copy the flight of winged animals.

The gossamer spider makes its aerial voyages by clinging to a light tangle of web, on which, as by a parachute, it is borne to great distances by the wind.

Many species have this habit of the gossamer. Some, however, use, instead of a tangle, long lines of web which are cast out upon the wind to a distance of several hundred feet, until their buoyancy becomes

* Ashmead, Orange Insects, page 3.

sufficient to sustain the weight of the little aeronaut, or until in its sweep it becomes entangled in the branches of a distant tree or shrub, and forms a bridge upon which the spider readily crosses.

The warm ascending currents of spring, the southeast trade-winds in Florida, excite multitudes of spiders to set out upon their travels, speeding them on their way and directing their course. At this season of the year, when the migrations of insects are at their height, and all nature is in restless activity, Scale-insects also are most abundantly productive, and the leaves and branches of infested trees swarm with their young. Thus it is that in spring especially the spiders, aided by the winds, carry the Bark-lice in numbers and to great distances.

*Conditions favorable to their Increase.*—There is good reason to believe that Bark-lice, like many other destructive insects, do not, as a rule, originate the disorders which follow their attacks. An enfeebled condition of the plant, from whatsoever cause it arises, is generally necessary to provoke an invasion. Thoroughly healthy trees, even when infected, may remain uninjured for years. The Scale-insects upon them thrive only upon the lower or inside branches, and are held in check by their natural enemies and parasites. An unfavorable atmospheric condition, such as long-continued drought, the impoverishment of the soil, neglect of cultivation, and the many obscure or utterly unknown causes which produce "die-back," yellow and streaked foliage, or other indications of vegetable indigestion, if such it may be called, all tend to foster Scale-insects and favor their rapid increase.

In explanation of these facts, it may be conjectured, although it is not, perhaps, susceptible of proof, that peculiar conditions of the sap are especially favorable to the development of Scale-insects, and affect the reproductive functions, stimulating the females to greater productiveness. Observations show that the number of eggs deposited varies considerably, and that the maximum number is produced, not by solitary females upon vigorous plants, but by individuals of the advancing brood taken from portions of the plant plainly affected by their attacks.

*Usual course of the Pest.*—If it be true that outbursts of Scale-insects commonly owe their origin to some disturbance in the condition of the plant, it is no less a fact that their ravages not only aggravate the original trouble, but entail others, it may be, far more serious in their consequences. The countless throng of Bark-lice not only weaken the plant by sapping and diverting its vital juices and depriving it of nourishment, but they also strangle the parts which they infest by coating the surface and clogging its pores with their myriad bodies. Their long, hair-like sucking beaks penetrate and thread the cellular tissues of the growing bark, breaking through and altering its structure so that the tender bark of the twigs and younger shoots is destroyed, while the thicker bark of the trunk and larger limbs hardens and becomes, as it is popularly termed, "hide-bound."

In this condition healthy growth is impossible. If neglected and allowed to be overrun by the pest, the growth of the tree is checked;

the infested twigs and branches die; often the entire top is lost. The roots and trunk, however, survive, and the tree endeavors to repair the injury by throwing out shoots from below.

When the tree reaches this impoverished condition matters usually begin to mend. The Bark-lice upon the dead or dying branches perish by starvation, the parasites reassert their sway, and slowly the tree regains its health and vigor, but seldom its pristine beauty.

The opinion is often expressed that the tree will "throw off the scales," or that they will "disappear in time at the ends of the branches." The facts upon which this belief is founded are simply that the young lice, when the branches become crowded, wander off and on to new growth; their course is, therefore, naturally upward and outward. When the advancing army reaches the ultimate branches, the insects crowd upon the smaller twigs and leaves, killing them rapidly and involving themselves in the common destruction. The tide of scales is then checked, while the enemies thrive and multiply, feeding upon the dead and starving Coccids. There then occurs one of those sudden oscillations of the balance which are familiar enough to entomologists; the unseen enemies increase and the scales visibly diminish. The tree meantime has rest and may under favorable circumstances recover its vigor, in which case the trouble for the time being is over, and the lost branches are quickly replaced.

More frequently, however, the new growth, which always pushes out rapidly in such cases, will, as soon as it hardens, be overrun by the crawling scale-larvæ, newly hatched from eggs which were not involved in the destruction of the mother insects, and after an interval a new brood will be found again in possession. This process may be repeated many times in the tops of full-grown trees, and the orange-grower at each ebb in the tide will perhaps flatter himself with the delusion that the scales have in some mysterious manner disappeared at the ends of the destroyed branches. Well-grown trees may submit again and again to these vicissitudes. They may even permanently recover without the aid of applied remedies, but very young orange trees do not possess the powers of resistance of adult trees; their tops being small and their branches short, they are usually entirely overrun in a single season, and, if not attended to, sustain irreparable injury, resulting, in the case of budded trees, in the destruction of the budded portion.

*Influence of Climate.*—The retarding action of cold weather upon the development of Scale-insects, and the acceleration produced by the higher temperature of the summer months, has already been mentioned. The influence of a warm climate is shown in the increased number of annual generations. The species of Diaspinæ found in the Northern States have all, or nearly all of them, a single generation, occupying the summer months. The same species have in the warmer portions of the United States at least two broods, and in the extreme South those species with which orange-growers have to contend produce not less than three and some of them more than four generations.

The long-continued heat of summer acts as a check upon the advance southward of those species which inhabit the North, and is probably a more important factor in determining the geographical distribution of many species than the frosts of the northern winter.

Indeed the notion that Scale-insects are destroyed by frosts is entirely erroneous. Their eggs withstand any ordinary degree of cold, and the insects themselves survive a freezing temperature that kills the plants upon which they feed. The winter climate of a land in which the open culture of the Orange is possible cannot be sufficiently rigorous to kill even the young of Bark-lice. In Florida the coldest weather merely serves to retard their development.*

*Natural Checks.*—The parasites of Bark-lice, some of which have already been mentioned, and the numerous enemies to be considered hereafter, are similarly affected by climatic conditions. Their broods increase in number as they extend southwards, and in the main their activity keeps pace with that of their prey. Ordinarily, therefore, the various checks upon their increase are sufficient to prevent the spreading of Bark-lice to an injurious extent, and, as we have seen, it is only at times that they increase so rapidly as to entirely outstrip their enemies and overrun the plant.

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*Mr. Joseph Voyle, in a report made to Professor Riley, and published in Bulletin No. 4, United States Department of Agriculture, Division of Entomology, gives the results of an elaborate series of experiments made by subjecting Scale-insects, with their young and eggs, to the action of low temperatures for varying lengths of time. In these experiments the Coccids were placed in a small tin cylinder and surrounded with a freezing mixture of ice and salt. The time of exposure was never less than one nor more than sixteen hours, and the temperatures ranged from 16° to 36° F. Eggs were killed when the minimum fell below 25° and were not killed at higher temperatures; the young Bark-lice were killed in every experiment. It is to be remarked, however, that an average time of nine days was allowed to elapse before the results obtained were considered final. As Mr. Voyle himself suggests, "Sometimes larvæ retain for several days an apparently natural appearance, leaving it doubtful whether their final death is the result of the temperature or want of food."

In regard to the eggs also it is probable that certain conditions not noted and not taken into account in these experiments vitiated the results, since they do not correspond with what takes place in the open air during severe frosts.

On this point Mr. Voyle himself gives evidence when he says: "During the past winter, 1882–'83, by some special observations, positive evidence was obtained that often very little damage was done to scale insects by cold that killed the tender orange shoots. On the morning of December 16, 1882, the thermometer was reported at various figures, from 19° to 25° F. My own lowest reading was 25°. On this morning I cut orange branches incrusted with scale insects, and found young migratory larvæ of *Mytilaspis* running about quite lively."

This discrepancy is remarked by Mr. Voyle, and the following explanation is suggested: "There are conditions practically unattainable artificially, where the coccids are protected from the effects of such temperature as under favorable conditions would be fatal to them. The leaves of the tree, the warm current rising from the ground around the trunk of the tree, and the initial heat of the tree itself perform an important part in modifying temperature for these insects. In a still atmosphere this might become a perfect protection against a temperature much lower than would prove fatal in other conditions."

# CHAPTER IV.

## LECANINÆ—THE NAKED OR WAXY SCALES.

*General Characters and Life-history.*—The Bark-lice of this subfamily make no true scale. They are either naked or possess waxy coats adhering more or less closely to the body of the insect, but not fastened permanently to the bark. The development from the larva to the adult female is apparently one of simple growth, and no molts have been observed. The change in form takes place gradually and is due to the swelling of the body as it becomes filled with eggs or young, or to the accumulation of the covering of wax. Eggs are deposited in a cavity beneath the body of the mother, or are retained within her body until hatched, in those species which bring forth their young living.

The young change their position upon the plant at will, and this freedom of movement is retained until near the end of their lives. The insects, however, become more sluggish as they grow older, and at last, in the incubating period, the legs and other external members of the larva wither and the body becomes adherent to the surface of the plant. No males have been discovered in any of the species of the group which come within the scope of this treatise.

The newly-hatched young of the Lecaninæ closely resemble those of the Diaspinæ. They are active, six-legged creatures, with thin bodies, oval in form. They feed in the same manner, by plunging their sucking beaks into the cellular tissues of the plant, but the beak never grows very long, and while active life remains the insect has power to remove it and to reinsert it in a fresh place.

Two genera of Lecaninæ fall within the scope of this work.

In the genus *Lecanium* the insect makes no covering for itself or its eggs, but the skin becomes more or less toughened with age, and finally presents the appearance of a parchment-like scale. The species belonging to the genus *Ceroplastes* excrete a thick coating of wax, which wraps the body of the insect above, but is easily removed from its surface. Underneath the wax the skin of the Coccid is thin and tender.

### *THE TURTLE-BACK SCALE—BROAD SCALE.*

(*Lecanium hesperidum*, Linn.)

[Fig. 11.]

*Descriptive.*—The full-grown Coccid is $3^{mm}$ to $4^{mm}$ (0.12 to 0.16 inch) long, broadly oval, more or less swollen, and convex upon the disk, surrounded by a thin, flat margin with two shallow notches on each side

and one deeper indentation behind. The color changes with age from transparent yellow in the young to deepening shades of brown in the adult. Individuals attacked by parasites turn black. Until it becomes gravid and swollen with young, the insect is exceedingly thin and transparent, the green color of the leaf or bark showing through the body so that the very young Coccid is well nigh invisible. The surface is smooth and shining, with faint, scattered punctures on the disk. The six slender legs are concealed beneath the dilated margins of the body. The male, although for many years diligently sought, both in this country and abroad, still remains undiscovered.

*Young Larva.*—The new-born insect has the usual oval form of young Bark-lice. It is yellowish in color, and has a pair of six-jointed antennæ, and two long bristles at the anal extremity.

*Metamorphoses.*—The metamorphoses which take place in this species are very simple, and consist in a flattening and broadening of the form of the larva, and in the gradual loss of external organs by disuse. The first to disappear are the antennæ and the anal bristles; lastly, but not until the body becomes swollen with young, the legs become useless, and are imbedded in the excretions, which finally cement the insect to the surface of the plant. The body of the mother in this last stage of her existence becomes a casket filled with the young lice. These in due time swarm forth together and distribute themselves over the plant.

FIG. 11.—*Lecanium hesperidum* (Linn.) Adult females, on Orange, natural size. (After Comstock.)

*Restriction to young Growth.*—The young lice invariably settle upon the bark and leaves of tender growth. Even the adult insects do not appear able to pierce with their beaks the tissues of the plant when hardened by age, and only the gravid and incubating females are found upon parts which have completed a season's growth.

*Gregarious Habits.*—There is a tendency in the young to keep together, and at seasons when the Orange is in active growth, when the plant is pushing out an abundance of shoots, the swarming larvæ do not need to wander far in search of food. The progeny of each female then settle down together, and extensive colonies are formed. These colonies

never long outlast the growing season. If not sooner exterminated by the attacks of enemies and parasites, the hardening of the tissues of the bark and leaves gradually puts an end to their existence, and the young of later generations must seek elsewhere for their support.

*Brood Periods.*—Thus, in spring and early summer, when the Orange renews its foliage and new growth is abundant, the increase of this insect is most rapid, and the number and extent of its colonies often become alarming. The month of June is generally the time of greatest activity in this species. Later in the season the colonies dwindle and become reduced to a few gravid individuals. The young are obliged to wander far in search of bark sufficiently tender to be penetrated by their beaks. This can be found only upon the solitary shoots and vigorous leaders, which the tree in summer sends upwards from the trunk or main branches below. It is not surprising, therefore, that very many of the young lice hatched in summer perish from hunger, being unable to find a spot penetrable by their beaks, or they fall a prey to numerous enemies in their wanderings over the plant, and in fall and winter, as a rule, only solitary individuals are met with.

*Excretion of Honey.*—From minute pores upon the sides of the bodies of these insects exudes a colorless nectar. This liquid may also be ejected by them with considerable force, so that it falls upon the leaves and parts of the plant at some distance away, and forms a sticky coating; but it is never in sufficient quantity to form drops, as sometimes happens in the case of other sucking-bugs which produce honey-dew. If not lapped up by other insects, the nectar attracts a black sugar fungus (*Capnodium citri*), and the plant becomes coated with "smut."

*Attended by Ants.*—Like all sluggish nectar-producing insects, the *Lecanium hesperidum* is attended by troops of ants, which feed upon the sweet excretions, and not only clean the surface of the leaves about the Bark-lice, but also lick the insects themselves, and with caressing strokes of their antennæ induce them to give out the liquid more freely. Ants, therefore, are not enemies of this Bark-louse; on the contrary they are its friends, and afford it more or less protection from the attacks of certain enemies. The extent of their services to the Bark-lice has been greatly exaggerated, however, and they cannot prevent their destruction by internal parasites.

As indicators of the presence of this Bark-louse, ants become useful to the observing cultivator, for if a tree is in the slightest degree infested, and long before the colonies of Lecanium become destructive or even noticeable, the tell-tale stream of ants ascending and descending its trunk gives an infallible indication of the impending evil and guides the eye to the secret lurking places of the pest.

PARASITES.—Colonies of the Turtle-back Scale are, however, seldom allowed to dwindle and dissipate themselves solely by the action of their own laws of growth and existence; they are subject to the attacks of internal parasites which greatly hasten their dissolution. These para-

sites are, as usual, minute Hymenopterous flies belonging to the family of the *Chalcididæ*. The destruction which they work upon colonies of the Bark-louse is so great that frequently it appears an accident due to oversight on the part of the parasites if among the throng an occcasional individual Coccid escapes. Among scattered and solitary individuals of Lecanium the destruction by parasites is less complete and many escape. If it were to remain strictly gregarious at all seasons of the year this now common Bark-louse would no doubt speedily become a rarity. The following four species of these parasites have been observed to prey upon *Lecanium hesperidum:*

*Coccophagus lecanii* (Fitch).—In this species the general color of the body is black, the crescent-shaped shield on the back between the wings is lemon-yellow in the female and brown in the male; eyes dark-red brown; antennæ light brown, with the tip of the club darker; wings clear, with dark-brown veins; thighs brown, yellow at the extremities, the remainder of the legs light yellow, with the last joint of the tarsi brown. The length varies from 1$^{mm}$ (0.04 inch) in the female to 0.5$^{mm}$ (0.02 inch) in the male.

This parasite lives upon several species of Bark-lice, and is found in all parts of the United States. In Florida it is the most common parasite of *Lecanium hesperidum*, and is seldom absent from its colonies. With rare exceptions a solitary specimen of Coccophagus occupies the body of each parasitized Lecanium. The Coccids are always attacked before they attain full growth. In dying they turn black and adhere firmly to the bark. The bloated and hardened skin of the Bark-louse forms a casket in which the parasite undergoes its transformation to a pupa of dark color, and from which it emerges in time as a perfect fly through a round hole eaten in the shell. If there are any distinct broods they coincide with those of the Bark-louse, and with the colonies of the latter the numbers of the parasite increase or diminish.

*Coccophagus cognatus* Howard (Fig. 12) is a somewhat larger species than the preceding, rather lighter (dark brown) in color. In the female the shield upon the back is orange-yellow; in the male the corresponding parts are tipped with light yellowish-brown. The front legs are fuscous, the middle and hind pairs darker; all the tarsi are whitish, with the last two joints dusky. Length of female 1.2$^{mm}$ (0.05 inch), of male 0.6$^{mm}$ (0.02 inch). This species, first noted and described by Mr. Howard (Report of Commissioner of Agriculture for 1880, p. 359), was bred from *Lecanium hesperidum* on orange trees in the orange house of the Department of Agriculture at Washington.

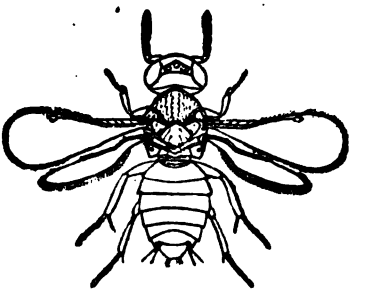

FIG. 12.—*Coccophagus cognatus.* (After Howard.)

The foregoing parasites, belonging to the genus *Coccophagus*, have eight-jointed antennæ. In the genus *Comys* the antennæ are eleven-jointed, the shield upon the back (*scutellum*) terminates in a tuft of long, stiff hairs, and the fore wings are clouded with brown.

FIG. 13.—*Comys bicolor*. (After Howard.)

*Comys bicolor* Howard (Fig. 13) is the largest parasite of *Lecanium hesperidum*. It has dark-brown eyes, head and face yellowish-brown, collar shining black, remainder of thorax yellowish-brown, with black hairs; abdomen shining black. The first and second pairs of legs are respectively dark and light brown, with the thighs white below, fuscous above; the hind legs dark, with silvery white tarsi; length 1.75mm (0.07 inch). This parasite is found in company with *Coccophagus lecanii*. Being larger it inhabits the full-grown scales, while the *Coccophagus* attacks only those which are partly grown. The Bark-lice which contain pupæ of this parasite turn black as with the preceding species.

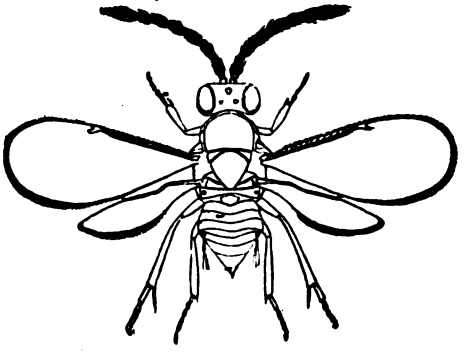

FIG. 14.—*Encyrtus flavus*, male. (After Howard.)

*Encyrtus flavus* Howard (Figs. 14 and 15).—In this species the antennæ are eleven-jointed, but the scutellum is lustrous and without the tuft of hairs. The sexes are very dissimilar. *Female*, general color ocher-yellow; eyes brownish; eyelets carmine; antennæ brownish, or yellowish at base, three intermediate joints brilliant white, club at the end black; the fore-wings dusky, clear at base, with a clear band across the middle, and two triangular clear spaces on the outer third. Length, 1.2mm (0.05 inch). *Male*, color shining metallic green, with bronze tinge on the back; legs light yellow, dusky at tips; antennæ dusky, yellow at base, the joints covered with long hairs. Length, 0.85mm (0.03 inch).

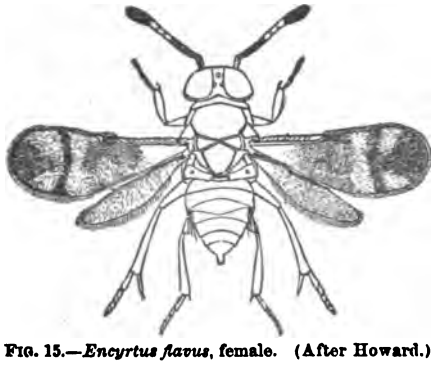

FIG. 15.—*Encyrtus flavus*, female. (After Howard.)

*Geographical Distribution and Food Plants.—Lecanium hesperidum*

(Linn.) is one of the best known and most widely distributed species of Bark-louse. For centuries it has been transported from one country to another, until it has become thoroughly cosmopolitan and a common pest in green-houses throughout the world. In mild climates, like those of southern Europe and the southern United States, it thrives in the open air. It is a general feeder, and although found most constantly upon plants of the citrus family, others in great variety are attacked. Marked preference is shown for plants with smooth bark and thick or glossy leaves; thus the Ivy, Oleander, and Japonica suffer equally with the Orange from the depredations of this Bark-louse.

### *THE BLACK SCALE OF CALIFORNIA.*

(*Lecanium oleæ* Bernard.)

[Fig. 16.]

The following account of this scale is found in the Report of the Commissioner of Agriculture for 1880, p. 336:

"***Adult Female.***—Dark brown, nearly black in color; nearly hemispheri-

FIG. 16.—*Lecanium oleæ* Bernard. 16, adult females on Olive, natural size; *a*, female, enlarged. (After Comstock.)

cal in form, often, however, quite a little longer than broad; average length from 4mm to 5mm; average height 3mm. Dorsum with a median longitudinal carina and two transverse carinæ, the latter dividing the

body into three subequal portions; frequently the longitudinal ridge more prominent between the transverse ridges than elsewhere, th forming with them a raised surface of the form of a capital H. Th body is slightly margined; outer part of the disk with many (18–3 small ridges which extend from the margin half way up to center dorsum. Viewed with the microscope, the skin is seen to be filled wit oval or round cells each with a clear nucleus; the average size of th cells being from .05mm to .06mm in length, while the nuclei average .02mm in diameter. The antennæ are long and 8-jointed, the two basal joints short; joint 3 longest, joints 4 and 5 equal and shorter, joints 6 and 7 equal and still shorter, joint 8 with a notched margin and almost as long as joint 3. Legs rather long and stout, the tibiæ being about one fifth longer than the tarsi. The anal ring seems to bear six long hairs.

"*The Egg.*—Long oval in shape, 0.4mm in length, yellowish in color.

"*Newly-hatched Larvæ.*—There is nothing very characteristic about the young larvæ; they are flat, and their antennæ are only 6-jointed.

"The black scale is stated by Signoret to be properly in France an olive scale, sometimes, however, becoming so common as to occur on all neighboring plants also. In California we find it infesting the greatest variety of plants, and becoming a very serious enemy to orange and other citrus trees. I have found it at Los Angeles on orange and all other citrus plants, on olive, pear, apricot, plum, pomegranate, Oregon ash, bitter sweet, apple, eucalyptus, sabal palm, California coffee, rose, cape jessamine, *Habrothmus elegans;* and elsewhere upon an Australian plant known as *Brachaeton*, and also upon a heath. It preferably attacks the smaller twigs of these plants, and the young usually settle upon the leaves.

"The development of this species is very slow; and it seems probable that there is only one brood in a year. Specimens observed by Mr. Alexander Craw at Los Angeles, which hatched in June or July, began to show the characteristic ridges only in November. Mr. Craw has seen the lice, even when quite well grown, move from twigs which had become dry and take up their quarters on fresh ones.

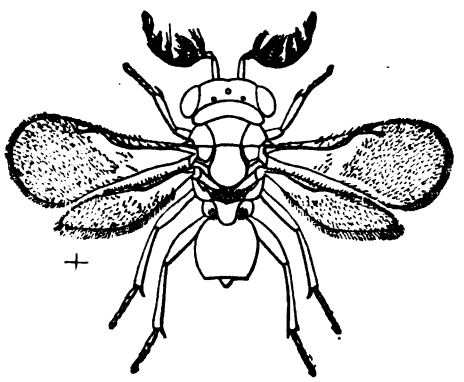

FIG. 17.—*Tomocera californica*, male. (After Howard.)

"Although carefully looked for, the males, like those of so many other lecanides, have never been found.

"A dark brown bark-louse has been sent me from Florida, on live oak, holly, oleander, orange, and one or two unknown plants, by Dr. R. S. Turner, of Fort George, which appears to be identical with *Lecanium*

*oleæ*. It is, however, by no means as abundant or injurious in that State as in California.

"*Natural Enemies.*—Enormous quantities of the eggs of the black scales are destroyed by the chalcid parasite *Tomocera californica*, described on p. —— [368] of this report. [Fig. 17, male; Fig. 18, female.] Particulars as to the work of this parasite are given at the same place. Upon one occasion (August 25, 1880), I found within the body of a full-grown female a lepidopterous larva, which was very similar in appearance to the larvæ of the species of *Dakruma* described in my last report as destroying bark-lice. The specimen, however, was lost, and no more have been found since.

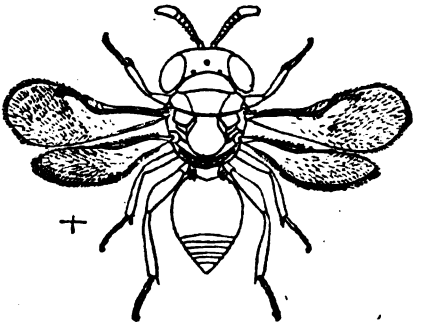

FIG. 18.—*Tomocera californica*, female. (After Howard.)

"A number of beetles of the genus *Latridius* were found under scales which had been punctured by the *Tomocera*, but probably would not destroy the live insect. Many mites were found feeding upon the eggs and young. The infested trees were also swarming with the different species of lady-bugs (*Coccinellidæ*)."

### *THE HEMISPHERICAL SCALE.*

(*Lecanium hemisphæricum* Targioni.)

[Fig. 19.]

Professor Comstock, in the Report of the Commissioner of Agriculture for 1880, p. 334, thus treats of this Bark-louse:

"*Adult Female.*—Shape approaching hemispherical with the edges flattened. Average length, 3.5$^{mm}$; width, 3$^{mm}$; height, 2$^{mm}$. The shape and proportions vary somewhat according as the scale is formed upon a leaf or a twig. Upon the rounded twig it loses something of its hemispherical form, becomes more elongated, and its flattened edges are bent downwards, clasping the twig. In such cases, of course, its height becomes greater and its width less. The color varies from a very light brown when young to a dark brown, occasionally slightly tinged with reddish when old. The oval cells of the skin vary in length from .01$^{mm}$ to .04$^{mm}$, and each cell contains a large granular nucleus. The antennæ are 8-jointed with joints 1 and 2 short and thick; joint 3 is the longest, and the succeeding joints decrease gradually in length to joint 8, which is longer than the preceding. Occasionally a specimen is found in which joint 5 is longer than 4, and I have seen individuals in which this was the case with one of the antennæ while the other was normal. The legs are long and rather slender; the bristle on the trochanter is long; the articulation of the *tarsi is very well marked.* (This fact has sug-

gested to Signoret that the insects of this series are less fixed than t congeners.) The tarsal digitules are, as usual, two long and two sl those of the claws spreading widely at summit, and very stout at base. The anal-genital ring (more easily seen than in the other sp we describe) is furnished with c long hairs. The anal plates ar angular with rounded corners, are furnished with two long l upon the disk, and three u shorter ones at the tip.

FIG. 19.—*Lecanium hemisphæricum* Targ. 19, adult females on Orange, natural size; *a*, adult female, enlarged. (After Comstock.)

"*The Egg.*—The egg is ellipsoic form, and 0.15$^{mm}$ in length. In i it is whitish with a yellowish t and is smooth and shining.

"*The newly-hatched Larva.*—Th tennæ are only 7-jointed, and tarso-tibial articulation is hi marked.

"This bark-louse was first no in the orangery of the Depart upon the leaves and twigs. It also noticed upon various g house plants, Disipyrus, Ch phyllum, sago palm, and *Croto riegatum*. Shortly after being f here it was received from c spondents in California as infe orange and oleander. During visit to California I found it up single orange tree in the yar Mr. Elwood Cooper, near Santa Barbara.

"Actual observation shows the surmise of Signoret as to the loc tive powers of this insect to have been correct. We have seen adult insects when removed from their positions crawl back with parent ease."

### *THE WAX SCALE—WHITE SCALE.*

(*Ceroplastes floridensis* Comstock.)

[Fig. 20.]

*Descriptive.*—The adult insect with its covering is from 2$^{mm}$ tc (0.08 to 0.12 inch) in length; oval in form, convex above, flatten concave beneath. The upper surface presents a rounded central p inence, and on the margins six or eight smaller prominences surro ing the central one, and separated from it by a well-marked depres Near the posterior extremity, at the bottom of a deep pit, is seen open end of a tube projecting from the body of the insect. The excr

covering is a soft wax, very similar to the white wax of commerce. The color is white, rendered impure by surface accumulations of dust and dirt. A faint tinge of pink is sometimes given to the semi-transparent wax by the red color of the insect beneath.

When the covering of wax is removed the naked body of the insect is disclosed to view. This has the form of an almost globular sack, with thin and delicate walls, inclosing dark red liquid contents, or eggs of similar color. The upper surface of the body bears six prominent tubercles, three on each side, and a short anal tube, the end of which, as has been seen, penetrates the covering of wax. Beneath the flattened ventral surface may be discovered the disused, but not wholly discarded, legs and antennæ of the larva. The under surface also usually shows the marginal notches, more plainly seen in Lecanium, and which indicates the three structural divisions of the body. From these notches radiate streaks of chalky white exudation, which at a hasty glance have the appearance of legs, but probably serve as a cement attaching the scale more firmly to the bark.

FIG. 20.—*Ceroplastes floridensis* Comstock. 20, adult and young females on Ilex, natural size; *a*, young femal., enlarged; *b*, adult female, enlarged. (After Comstock.)

*Larva.* — The newly-hatched louse has the usual oval, flattened form. Color pale ruddy brown, with the members yellowish; antennæ 6 jointed, tipped with long hairs. The caudal bristles are very long.

Eggs 0.25$^{mm}$ long, elliptical, having the color of sherry wine.

*Life-history.*—The eggs, to the number of seventy-five or one hundred, are deposited under the covering of the mother, and are simply transferred from the inside to the outside of her body, which becomes excavated below, and is more and more depleted as the process of laying goes on. At last, entirely collapsed, it forms a mere lining to the walls of the waxen casket, beneath which the eggs are brought to maturity and hatched.

The young, escaping from beneath the scale, scatter in all directions over the tree, and soon attach themselves, by their beaks, to the surfaces of the leaves. After they have begun to feed and to excrete wax,

they are rarely seen to move by day, but at night they frequently change their position. Finally they desert the leaves, and at maturity the greater number will be found upon the bark of the twigs and smaller branches.

The excretions of wax exude from minute orifices called spinnerets, placed in groups upon various parts of the body, but chiefly upon the margins. At first the wax forms in ridges, which unite and form a crown around a central tuft. Smaller tufts to the number of a dozen or fifteen arise about the central elevation, and the young louse, when about a week old, appears as an oval white star upon the leaf. The wax gradually spreads over the surface of the insect, and for a time forms distinct plates; six of these, three upon each side, are large and distinct; the three remaining plates are small; they are situate one at each end and one in the center. After the insect has attained two-thirds its adult size, the plates are found to have coalesced, and form a thick, continuous sheet of wax, from which arise at least as many tufts as there were plates. The tufts, which are merely exfoliations of wax, marking the spots where the material is most abundantly given off, slowly but constantly melt into the surrounding mass. At full maturity, when the production of wax entirely ceases, these eruptive centers become obliterated, or are marked by a few projecting fragments which gather dust and dirt and cause discolorations and spots which have been variously described by different authors.

The honey-dew produced and given off by these insects attracts ants and other insects, and, as in the case of Lecanium, these lap the nectar from the bodies of the Coccids and from surrounding objects.

*Broods.*—The development of this insect is not very rapid, and extends over three or four months. The principal broods are in spring (April and May) and in midsummer (July and August). A third brood occurs in October or November.

*Habitat and Food Plants.*—This Bark-louse is found in all parts of the peninsula of Florida, but is not known to occur elsewhere. Its principal food plant is the Gall-berry (*Ilex glabra*), a plant which grows abundantly in the sterile "flat woods" and in low ground about ponds. In these waste places, often far removed from cultivated plantations, the insect may be found in such abundance that the stems of the gall-berry bushes are loaded with them in dense clusters, while the leaves and all surrounding objects are coated with the black smut which always accompanies crowded colonies of this and other nectar-yielding Coccids. Such infested patches of Gall-berry sometimes cover acres in extent.

Although the insect lives and thrives upon many other plants, and particularly upon such fruit trees as the Quince, Apple, and Pear, which in Florida do not find suitable climatic conditions, and are not thrifty, yet in cultivated orchards it is seldom destructive. Upon the Orange it occurs everywhere in numbers usually insignificant, but at times sufficient to excite apprehension. The white color and striking stellate

form of the young, dotted over the glossy surfaces of the leaves, frequently attract attention, but their numbers are always so greatly reduced during growth that only three or four per cent. reach the adult age.

The thinning-out is not alone the work of enemies and parasites, but is also due to the fact that the lice, when they become gravid, cannot maintain their hold upon the smooth surface of the leaves. They fall to the ground and perish, being in the latter portion of their lives incapable of free movement and, therefore, unable to reascend the trees. The Orange is not, therefore, adapted to this species of Scale-insect, and is never subject to long-continued or very damaging attacks by it.

The occurrence of this Bark-louse upon wild plants, in portions of Florida very remote from cultivation, seems to indicate that it is indigenous, and not imported as supposed by Mr. Ashmead, who, however, considers it identical with *Ceroplastes rusci* (Linn.), a common European species. Professor Comstock, who has carefully compared the Old World species with our own, remarks that *C. floridensis* "presents several marked differences; the most easily noticeable being the small size of the central plate, and its entire disappearance so early in the life of the insect."

*Parasites.*—A small Hymenopterous fly has been bred from *Ceroplastes floridensis*. It is similar in appearance and habits to *Encyrtus flavus* Howard, previously mentioned as preying upon *Lecanium hesperidum*.* In his paper on parasites of the Coccidæ (Report Comm. Agric. for 1880, p. 369), Mr. Howard notices the occurrence of an allied parasite, a species of the genus *Tetrastichus*, which also remains undescribed.[1]

### *THE BARNACLE SCALE.*

### (*Ceroplastes cirripediformis* Comstock.)

[Fig. 21.]

The following account of this somewhat uncommon scale is given by Professor Comstock (Report Commissioner of Agriculture for 1880, p. 333):

"*Adult Female.*—Average length $5^{mm}$; width, $4^{mm}$; height, $4^{mm}$. When naked the color is dark reddish brown; the shape sub-globular, with a strong spine-like projection at the anal end of the body. The waxy covering is dirty white, mottled with several shades of grayish or light brown, and even in the oldest specimens retains the division into plates, although the form is more rounded and the dividing lines by no means as distinct as at an earlier age. There are visible a large convex dorsal plate, and apparently six lateral, each with a central nucleus; the anal

* This may be *Aphycus ceroplastis* Howard, described in Bulletin 5, Bureau of Entomology, as bred from *Ceroplastes artemesiæ* Riley MSS., from Silver City, N. Mex.

plate, however, is larger, and shows two nuclei, and is evidently two plates joined together. Antennæ 6-jointed, and proportioned as with *C. Floridensis*. Legs long; tibiæ nearly twice as long as tarsi; digitules of the claw very large. The other tarsal pair very long and slender, but with a very large button. The skin is seen in places to be furnished with many minute, round, transparent cellules, probably *spinnerets* (indicated and so called by Signoret in his description of *C. Vinsonii*), and along the border are small groups of the constricted arrow-shaped tubercles mentioned in the last species; but the bristle-shaped *spinnerets* seem to be wanting, as in *C. Fairmairii* Targ.

FIG. 21.—*Ceroplastes cirripediformis* Comstock. Adult females, natural size; *a*, female, enlarged. (After Comstock.)

"*The Eggs.*—Length, 0.35mm, rather slender, little more than a third as thick as long. Color light reddish brown, rather darker than the egg of *C. Floridensis*.

"*Young Larva.*—Very slender; dark brown in color; legs and antennæ as with *C. Floridensis*.

"*Growth of the Insect.*—The growth of the insect and the formation of the waxy covering seems to be very similar to that of the last species. Soon after the larva settles the same two dorsal ridges of white secretion make their appearance, but soon split up into transverse bands. Examined on the fifth day after hatching, a larva showed seven distinct transverse bands, the anterior one being in the shape of a horseshoe. At the same time the lateral margin of the body was observed to be fringed with stiff spines, seventeen to a side. At nine days the small horse shoe-like mass had extended so as to nearly cover the thorax, and the transverse bands had lengthened and widened until they presented the appearance of a nearly complete shield to the abdomen, serrate at the edges. Fifteen lateral tufts, such as were noticed in *C. Floridensis*, and such as Targioni figures in the larva of *C. rusci* (Stud. Sulle coccinigliе, Plate 1, Fig. 6) had appeared, though still small.

"At this stage of growth, as with the last species, all development seemed to stop, although the specimens lived on for months, the temperature in the breeding-room probably not being favorable to the formation of the plates.

"The smallest specimen in the collection with the plates already formed measures 2mm long by 2mm wide and 1mm high. The color is light brown, and the wax has a somewhat translucent appearance. The dorsal plate

ı-sided; it is truncate anteriorly and pointed posteriorly. From ıgle radiates a suture to the lateral edge, thus forming seven plates, of which a single one is above the head, while above the the suture between two. Through this suture projects the anal Each plate has a dark brown patch in its center, and in the cen- ach brown patch is a bit of the white secretion.

*bitat and Food-plants.*—Found at Jacksonville and in Volusia , Florida, on orange, quince, and on a species of *Eupatorium*, ı company with with *C. Floridensis*, although it was by no means non a species."

## GENERAL REMARKS UPON THE LECANINÆ.

*ıt of Injuries.*—The Bark-lice of this group are less injurious to trees ody plants than their hard-shelled relations, the Diaspinæ. Of ; species of Lecaniuæ which have been known to attack citrus the widely-distributed *Lecanium hesperidum* (Linn.) is most com- Florida, and is generally recognized and somewhat feared by growers. It is known to occur also in the orange districts of Cali- where, however, it does not appear to be destructive. The deci- which this unprotected scale suffers through the attacks of para- ıd enemies, and the consequent short life of its colonies, effect- nits its destructive powers. Very frequently the orange-grower ome aware of its presence only to find it in its decadence and the he colony virtually extinguished through the activity of his in- friends. This fortunate condition will be sufficiently indicated black color of the scales which are blasted by the presence of ;s.

ı-ive invasions of *Lecanium hesperidum* have never been known r, in this country at least. The injuries which it inflicts in groves are confined for the most part to nurseries or young :fore they have become fully established. Upon older trees only portions, and particularly shoots in process of hardening, are found to be infested. Rarely indeed does this scale occupy ire top of a grown orange tree. Still more rarely is an entire l overrun by it.

ıpecies of this group having soft bodies, which dry up and shrivel :ath, become loosened or washed by rains from their attachment bark, and soon disappear from trees. They do not, as in the the Diaspinæ, remain and form a permanent coating upon the logging its pores and exercising a baleful influence upon the of the tree long after life in the insects themselves has become

Black Scale of California, *Lecanium oleæ* Bernard, is, as its name :s, an olive scale. In California, however, it is quite injurious ›range and its kindred, and is said to be spreading upon decidu-

ous orchard trees in the more northern portions of the State. It is not distributed in Florida, but has certainly been introduced and is occasionally seen upon imported plants, particularly upon the Olive.

*Lecanium hemisphæricum* Targioni, according to Professor Comstock, has been found upon the Orange in California. It is not known in Florida.

Of the two species of wax scales, both of which are confined to Florida, *Ceroplastes floridensis* Comstock is by far the more abundant. *C. ciripediformis* is found in certain localities, but is rare or unknown throughout a large part of the orange district. Serious injuries rarely, if ever, result from the attacks of the wax scales on orange trees, although the young of the first named species are frequently sufficiently numerous to attract attention and excite alarm. They invariably disappear, however, or become reduced to a few solitary individuals, whose numbers barely suffice to perpetuate their race.

*Smut.*—The attacks of the various species of Lecanium or Ceroplastes are frequently accompanied by the appearance of the sugar fungus, *Capnodium citri* Berk. and Des., of which mention has been made in the introductory chapter of this work. The soot-like coating of the fungus covers leaves and bark, and even the Coccids themselves, feeding evidently upon the nectar which these insects have the power to eject to a considerable distance, and not upon the juices of the plant. In proof of this fact it may be mentioned that a similar black coating appears at times upon objects when smeared with the nectar produced by flowers, and it is always found upon sugar-cane, where the joints are not too much exposed to the light.

Not only does smut mask the operations of Scale-insects, so that it is not unfrequently mistaken for the cause of the ruin which they work, but it can hardly be doubted that it is itself directly injurious in clogging the pores and stifling the vital action of the growing parts of the plant. A coating of soot, to which this fungus bears so strong a resemblance, would, it may well be supposed, have an equally deleterious effect, particularly if, like the smut, it were applied to the plant with a coating of some viscid liquid.

# CHAPTER V

## COCCINÆ: THE MEALY-BUGS.

*General Characters and Habits.*—Bark-lice, belonging to the subfamily Coccinæ, cover themselves and their eggs with masses of downy wax of white color, and hence they receive the name Mealy-bugs. Beneath the flocculent covering the Bark-louse lies concealed, sometimes nestling beside a mass of eggs so large as to quite overshadow the insect itself, sometimes surrounded by a crowd of young lice, whose successive generations in a short time cover the surface of an infested plant with incrustations of dirty-white color resembling mildew.

The Mealy-bugs retain their legs, antennæ, and other organs of the larva, and to a great extent their freedom of motion throughout their lives.

As in the last subfamily, development in the female is very simple, and there is but slight change of form from the larva to the adult. The males of this group form a pupa, and develop into two-winged flies, like those of the armored scales, and while undergoing these changes they encase themselves in little sacks of flocculent wax.

Compared with other Coccids occurring on the Orange, the Mealy-bugs are of large size. In destructiveness they rival any of the preceding species. They secrete and eject honey-dew, and this, falling upon the leaves and upon the insects themselves, gives rise to the black smut fungus (*Capnodium citri*). The incrustation formed by the mealy bodies of the insects, befouled with smut, presents a very unsightly appearance, and trees smitten with these pests become conspicuous objects, visible at long distances.

*Food Plants.*—The Common Mealy-bug, *Dactylopius adonidum* (Linn.), is a well-known pest of the garden and greenhouse, attacking nearly all plants, even pines and evergreens, and undoubtedly including the Orange and its kind, at least in the gardens of southern Europe. In the United States, however, this species has not been known to infest orange groves, but its place is supplied by a very closely-related form, which is considered by Professor Comstock a new species of the same genus, and has been described by him under the name *D. destructor*. The habits of this and the following species, *Icerya purchasi* Mask., are similar, and, like the common garden insect, they attack, with disastrous results, almost all varieties of fruit and shade trees, as well as shrubs and herbaceous plants of the most widely different sorts.

### *THE DESTRUCTIVE MEALY-BUG.*

(*Dàctylopius destructor*, Comstock.

[Figs. 22 and 23.]

This species has been for several years very destructive to orange trees in groves and gardens in the neighborhood of Jacksonville, Fla., but although this, or some other species with difficulty distinguished from it, attacks the pineapple, Banana, Guava, and other tropical plants, no species of Mealy-bug has hitherto been reported as a pest in orange groves in the more southern portions of the State.*

Prof. J. H. Comstock gives the following account of this insect: †

"*Adult Female.*—Length, 3.5$^{mm}$ to 4$^{mm}$; width, 2$^{mm}$. Color, dull brownish yellow, somewhat darker than with *D. longifilis;* legs and antennæ concolorous with body. The lateral appendages (seventeen on each side) are short and inconspicuous and are subequal in length. Upon the surface of the body the powdery secretion is very slight. In spite of the small size of the filaments, the *spinnerets* and the supporting hairs are as numerous and as prominent, or nearly so, as in *D. longifilis;* those upon the anal lobes being especially long. Antennæ 8-jointed; joint 8 is the longest and is twice as long as the next in length, joint 3. After 3, joints 2 and 7, subequal, then 5 and 6, joint 4 being the shortest. The tarsi are a little more than half the length of the tibiæ and the digitules are as in the preceding species (*D. adonidum*); claws strong.

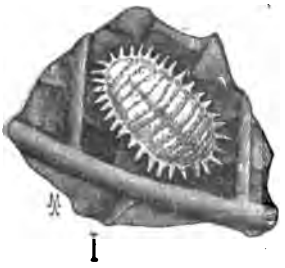

FIG. 22.—*Dactylopius destructor* Comstock; female, enlarged. (After Comstock.)

"*Egg.*—Length, 0.25$^{mm}$; shape, rather long, ellipsoidal; color, light straw-yellow.

"*Young Larva.*—Rather brighter colored than the egg. Antennæ 6-jointed with the female, with the same relative proportions as in the preceding species. Tarsi considerably longer than the tibiæ. The lower lip is large, conical, and reaches almost to the posterior coxæ.

"*Male.*—Length, 0.87$^{mm}$; expanse of wings, 2.5$^{mm}$. Color light olive-brown, lighter than in following species (*D. longifilis*); legs concolorous with body; antennæ reddish; eyes dark red; bands darker brown than the general color; anterior edge of mesoscutum and posterior edge of scutellum darker brown. Body, as will be seen from measurements, rather small and delicate compared with the size of the wings; head small, with almost no hair; antennæ 10-jointed, joints 3 and 10 longest and equal; joints 2, 6, 7, 8, and 9 nearly equal and considerably shorter

* Local outbreaks of the Mealy-bug are from time to time reported in the central portions of the peninsula. (See Appendix I.)

† Report of the Commissioner of Agriculture for 1880, p. 342.

than 3 and 10; joints 3 and 4 subequal and a trifle shorter than the following joints. The lateral ocelli are each just laterad of the center of the eye, and not at its posterior border, as in the following species. (This, however, is a character which will not hold with specimens long mounted.)

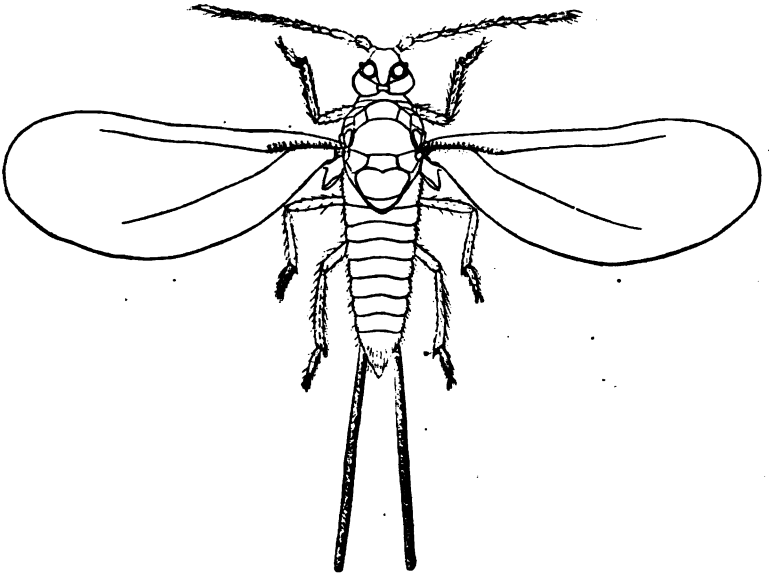

FIG. 23.—*Dactylopius destructor* Comstock, male. (After Comstock.)

Prothorax short; legs sparsely covered with hairs; tarsal digitules extremely delicate, and the button is very difficult to distinguish; we have been unable to discover a trace of the pair belonging to the claw. The anal filaments and the supporting hairs are similar to those of the following species.

"This species is readily distinguished from *D. longifilis* by the shortness of the lateral and anal filaments in the female. Indeed, for convenience's sake, we have been in the habit of distinguishing them as the mealy bug with short threads and the one with long. The life-history of this species differs quite decidedly from that of *D. longifilis*, in that true eggs, which occupy quite a long time in hatching, are deposited. The female begins laying her eggs in a cottony mass at the extremity of her abdomen, some time before attaining full growth, and the egg-mass increases with her own increase, gradually forcing the posterior end of the body upwards until she frequently seems to be almost standing on her head. The young larvæ soon after hatching spread in all directions and settle—preferably along the mid-rib on the under side of the leaves, or in the forks of the young twigs, where they form large colonies, closely packed together. As mentioned in the description, they are only slightly covered with the white powder, and many seem to be entirely bare, with the exception of the lateral threads.

"*Habitat.*—This species is very abundant upon almost every variety of house-plant in the Department green-houses, but especially so upon the Arabian and Liberian coffee-plants. On these plants they were found, curiously enough, in small pits or glands on the under side of the leaf, along the mid-rib. Almost every pit, of which there is one at the origin of each main vein, contained one or more young mealy bugs, and the larger ones whole colonies. The name *destructor* is, however, proposed for this insect from the damage done by it to orange trees in Florida, especially at Jacksonville and Micanopy, where it is the most serious insect pest of the orange.

"*Natural enemies.*—The Chalcid parasite, *Encyrtus inquisitor* Howard [Fig. 24], described in this report, was bred from a specimen of this mealy bug collected at Jacksonville, Fla. A small red bug was observed by myself and several of our correspondents to prey upon the mealy bug. The larvæ of another species have been found, but the mature form has not been obtained. These last have the faculty of changing color quickly from red to brown.

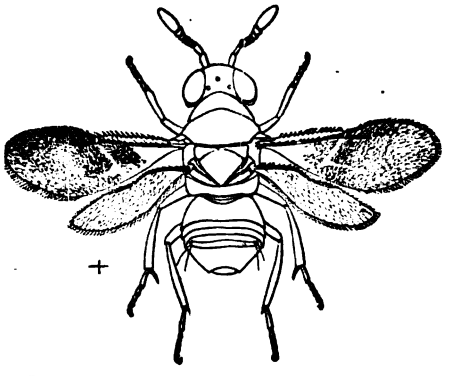

FIG. 24.—*Encyrtus inquisitor.* (After Howard.)

"The very curious larvæ of a lady-bird beetle, known as *Scymnus bioculatus*, were found feeding upon the eggs of the mealy bug at Orange Lake. These larvæ mimic the Dactylopii so closely that they might easily be taken for them. They are covered by a white secretion, and from each segment exudes a white substance which forms long filaments like those of the mealy bug. Removing the powder the larvæ are seen to be yellow in color, with two roundish dusky spots on the dorsum of each thoracic segment. Each segment of the body is furnished laterally with one long bristle and a number of small ones."

Two other parasites on *Dactylopius destructor* have recently been described by Mr. Howard (Bulletin 5, Bureau of Entomology, U. S. Dept. Agric.) as *Leptomastix dactylopii* and *Chiloneurus dactylopii.*

### *THE COTTONY CUSHION SCALE.*

(*Icerya purchasi*, Maskell.)

[Fig. 25.]

This insect has not yet been introduced into Florida. The following excellent account of it is from the pen of Dr. S. F. Chapin, State Horticultural Officer of California:*

* Pacific Rural Press, October 28, 1882.

"This scale has been, it is asserted, known to be on the acacia for seven years in San José, but it is only during the past and present seasons that it has attracted attention. Its great prolificness and its destructive abilities have called widespread attention to it. This pest attacks everything in the way of tree, vine or shrub; all the evergreens as well as deciduous trees that fall in its way are attacked, and every ornamental shrub on the lawns of some portion of our cities will show its presence. The ivy, even, is not proof against it. In San Rafael, San Mateo, Santa Barbara and Los Angeles it is well established. While in San José it has not this season caused so great damage as last, yet in the citrus-growing regions it is becoming one of the most serious pests they have to encounter, and it is even stated that, should its ravages not be checked, orange and lemon culture will have to be abandoned.

"From the rapid destruction which follows the presence of this scale, it is well that it should be widely recognized, and its first invasion noticed and checked. In San José, in 1881, it was first noticed in May as the fully developed female, from which the first brood of young then appeared.

"This present season of 1882 the first young appeared May 25th, the mother insect having gradually matured her eggs from the opening of spring until the young were hatched. The egg of the *Icerya* is small, pale or orange red, elongated and ovoid. The young just hatched out are very active, and are very minute, perhaps the twenty-fifth of an inch in length. The body is pale red; the six legs and two antennæ are black. The antennæ are long and club-shaped, and have from six to nine joints, as they are further matured. The antennæ are covered with long hairs, which bristle forth prominently. The eyes are small and black. Between the pair of forelegs on the under side of the body is to be seen the beak or sucker, by which the insect secures its nourishment.

"The females partly grown are of a variety of colors, orange red mostly, and spotted over with white and green; some are nearly entirely a dirty white, and many are a pea green. It seems that the coloring matter of the plant they are upon colors them to some extent. Their body is ovoid and elongated and flattened, the back being ridged up with several segments quite prominent. Around the rim of the body are a multitude of hairs, standing out prominently. Around the rear half of the body on its rim are a row of tubercles or spinarets, from which a white secretion issues, forming a cottony cord, and these placed side by side and the interspace filled up by the same material running lengthwise the body and projecting from it, gives the whole a ribbed, satin-like appearance whitish in color. Gradually as the insect matures these projecting ridges approach each other at the ends, and are joined together and curved under slightly at the point, while the sides are at the same time curved under the whole length, and the edges joined

together like a flat ribbon-like band, the whole forming, when complete, a soft elastic white sack, the size, and somewhat the shape of a medium sized white bean. The length, when mature, is about three-eighths of an inch; the width one-fifth of an inch.

"Inside the sack are deposited the eggs of the female, among the interstices of a mass of cotton-like fiber, which under a high magnifying power is shown to be round, and not more than one-sixth part the thickness of pure cotton fiber, with which it was compared in the same field. This mass of cottony fiber is filled with a great amount of granular matter, for the purpose, it may be, of affording sustenance to the young insects within the sack. The young hatch out in this sack, and make their way out into the world through a rent in the soft and tender underside of the sack.

"The female, after finding her home and during maturity, does not move, although she does not lose her legs, but clings tenaciously with her feet to her support, leaving the body tipped up in the rear and the cottony mass movable in any direction. The male insect was only found during a period of about two weeks from Sept. 25th. This was the observation of 1881, when I found them in great numbers. I have failed to find the male insect this season. It has a long red body, six legs and one pair of very long, dark and transparent wings, prominent eyes and antennæ very long and covered with hairs, arranged very much as the feathers of a peacock. (The antennæ are 16 or 17 jointed.)

FIG. 25.—*Icerya purchasi* Maskell. Females, adult and young, on Orange. (After Comstock.)

"The winged male is easily seen and easily caught, as it moves slowly about, and is not readily disturbed so as to fly away. The female insect lives upon the trunk of the tree and large limbs and down to the smallest twigs, around which it may be seen clinging in clusters sufficiently great to completely hide the branch; also upon the leaf, along the stem and ribs of which it is fixed, both above and below, although more abundant on the underside of the leaf.

"There are three broods of this insect in the season; the first appearing in May, the second in August and the third in October, or about three months apart. I have just observed, October 15th, the mature female with eggs fully grown and with the young hatched out and crawling in the same sack. In 1881 they rapidly increased from about the first of August, and were continually appearing, and still hatching out in December.

"Every female, it is estimated, produces from 200 to 500 young. The young will mature and produce a new brood in about three months."

# CHAPTER VI.

## INSECTS PREYING UPON BARK-LICE.

[Plate VI.]

Numerous enemies prey upon Bark-lice in all their stages, and always greatly reduce their numbers. Besides occasional enemies, such as the sucking-bugs and other predatory insects, which are general feeders, there are others which live almost or quite exclusively upon the Coccidæ. Some of these confine their attacks to particular kinds of Scale-insects. Several very common beetles of the family *Coccinellidæ*, the "Lady-birds," are useful destroyers of Bark-lice. One of the smallest of this family, *Hyperaspidius coccidivorus*, is found to colonize upon the trunks of orange trees thickly infested with Chaff Scale, and entirely free them of the pest. The young of a Lace-wing fly (*Chrysopa*) feeds upon the Bark-lice in all stages, and frequently makes its case of scales torn from the bark and often still containing living occupants. The Orange Basket-worm (*Platæceticus gloveri*) has the same habit, and the caterpillars of at least two moths are Bark-louse eaters. One of these (an unknown Tineid)[2] inhabits silken galleries, which it covers with half eaten fragments of scales, and performs such efficient service that every scale in its path is removed from the bark and suspended in the investing web.

The most important external enemies of the Scale-insect are certain mites, which are omnipresent upon trees infested with scale, and which feed upon the eggs and young lice. They breed rapidly and lurk in great numbers under old deserted scales, where their eggs are extremely well protected from the action of insecticides. For this reason, when an effective application has been made by spraying infested trees, the trunks should not be scraped for some time after, but the dead scales should be allowed to remain upon the bark for several weeks, in order that the mites which they harbor may be given time to complete the work of the remedy used. In this they may be confidently relied upon as powerful auxiliaries. When large numbers of the scales have been killed by spraying with oils, &c., the mites are often observed to increase suddenly, as they are much less affected by the application than the Scale-insects themselves. It seems probable that they feed upon the dead and dying Coccids as well as upon the living, and the loosening of the scales and abundance of food at such times stimulates them to rapid increase. They soon swarm in such numbers as completely to exterminate the remnant of the Coccids left alive by the wash.

Of all its enemies, the most efficient destroyers of the Scale-insect are its hymenopterous parasites; several species of which have already been noticed, each under the head of the particular Coccid with whose life history it is closely connected. Fig. 1 on Plate VI represents the common parasite (*Aphelinus mytilaspidis*) of the Apple Scale. These minute four-winged flies bore through the scale and deposit within a single egg. The little grub hatching from this egg feeds upon and destroys the occupant of the scale and completes its own transformations in its place. When fully adult the parasite emerges through a round hole eaten in the shell, leaving behind an empty domicile to serve as a shelter for the mites.

The numerous species of these parasites, although not invariably confined in each case to a single species of Bark-louse, have distinct methods of attack from which they do not vary. Thus the Long and the Purple Scales are parasitized at about the time of impregnation of the females, or when they are not more than one-half their adult size, and the young Hymenopteron is developed entirely within the body of the Coccid. The skin of the latter hardens when life is extinct, and doubly protects the parasite during the latter part of its larval and in its pupa stage. The parasite of the Chaff Scale makes its attack at a later stage, often when the scale is full of eggs, and its larva does not enter the body of the Coccid, but feeds upon it and the eggs indiscriminately, occasionally devouring the eggs alone and leaving the mother Coccid untouched. Its pupa is formed naked within the scale, and has only such protection as this affords the Coccid and its eggs. In individual numbers these hymenopterous parasites abound to such an extent that rarely less than 25 per cent. and often more than 75 per cent. of the scales are attacked by them, and the work of destruction accomplished through their agency alone equals if it does not excel that of all other enemies combined. Doubtless without their aid the culture of the Orange and related trees would, in Florida at least, become impracticable.

### *INSECTS OF THE ORDER HYMENOPTERA.*

ANTS.—No species of field-ant, in Florida at least, is in any sense predatory upon Scale-insects. With the hard-shelled Diaspinæ ants do not concern themselves, except that most of the carnivorous kinds will feed upon the contents of a scale which they chance to find torn from the bark. Many of the softer Coccidæ are attended by ants and to some extent protected by them, for the honey which they produce, and upon which the ants feed greedily without in the slightest degree harming or even disturbing the Coccids themselves.

The Chinese, it is said, have an ant which is really predatory upon Scale-insects, and which they colonize in some manner about their trees for the purpose of clearing them of these pests. If such a species exists, its importation to this country would be a great boon and could undoubtedly be accomplished. There is in fact nothing impracticable

in the idea of domesticating ants and in keeping them with their nests in movable hives, as we do bees.

We have in Florida a minute yellow ant, very common, and very troublesome in houses, which might perhaps be employed in this way. This species seeks the shelter of buildings and hollow tree-trunks; it has not as yet been found possible to induce them to remain domiciled in exposed situations, and to attack the Scale-insects upon living trees in the open air; but when branches covered with scale are brought into the house, they are voraciously attacked, the scales eaten into or torn from the bark and their contents devoured. The nests of this ant are found in very dry and sheltered situations. It is not difficult to establish a colony in a box filled with shavings, paper, or other loose material. In order to accomplish this, one or more of the large queens must be obtained and confined with a sufficient number of the workers to act as attendants. If the box is kept in a suitable place, the ants will accept their new quarters, and may be allowed to roam at large and forage for themselves and their young, but the slightest exposure to light or dampness will cause them to desert the hive never to return. It is this dislike of exposure that has hitherto baffled every endeavor to colonize this ant upon orange trees and use it as a destroyer of the Scale-insect. Further experiments with this and other species are necessary to determine whether any of them can be effectively employed against Scale-insects.

### *INSECTS OF THE ORDER COLEOPTERA.*

#### LADY-BIRDS—*Coccinellidæ.*

The beetles of this family are among the most efficient destroyers of Bark-lice and also of Plant-lice. Formerly they were supposed to feed exclusively upon small insects of various kinds. Although it is now known, through the investigations of Prof. S. A. Forbes and others, that the spores of fungi and other vegetable matter constitute a large part of the food of our common species, they are not on that account the less valuable in the orange grove.

The family contains numerous genera and species which fall into two divisions; the first, containing the species of larger size, includes the common insects, which are popularly recognized as "Lady-birds"; the second division embraces nearly all the smaller kinds, many of them insects of minute size, but very voracious and active destroyers of plant-eating insects and their eggs.

THE TWICE-STABBED LADY-BIRD (*Chilocorus bivulnerus*, Muls.). [Fig. 26, beetle; Fig. 27, larva.]—This species is $5^{mm}$ ($\frac{2}{10}$ inch) long, nearly hemispherical in shape, shining black, with a red spot on each wing-case.

The larva is rather broadly oval, the color bluish-black, with the first body-joint whitish. The body bristles with black spines, which are in

turn covered with spinules and give to the insect a mossy appearance. The spines are arranged in six longitudinal rows.

FIG. 26. — *Chilocorus bivulnerus.* (After Riley.)

The larva, when full grown, attaches itself firmly by the false legs at the end of the body, and becomes wedge-shaped; the skin of the back splits and gapes open, partly disclosing the pupa, which, however, remains within the skin of the larva. This mode of pupating is characteristic of the entire family.

The pupa is short and thick, tapering suddenly behind, in color black, mottled with dusky brown. The stout spines of the larva are replaced by patches of spiny hairs.

FIG. 27. — *Chilocorus bivulnerus.* Larva. (After Comstock.)

The Twice-stabbed Lady-bird is as abundant in Florida as in all parts of the eastern and southern United States, and, with its larva, is frequently seen upon the orange trees, feeding upon Scale-insects and also upon Aphis. It is rather fond of cool, damp situations, and is most abundant in old groves, upon the trunks of trees infested with Chaff Scale and fungi. It tears up the scales and devours the Coccids and their eggs. Several broods occur during the year. The larvæ appear to be somewhat gregarious, and frequently when they form their pupæ suspend themselves in clusters to shreds of Spanish moss or in patches upon the bark when it is coated with lichens.

EXOCHOMUS CONTRISTATUS Muls. (Fig. 28, beetle; Fig. 29, larva.)— This is a much smaller species than the preceding. The beetle is 3.3mm (0.13 inch) long. The head, thorax, and body beneath are black, but the wing-cases are red, with a black spot near the tip of each.

FIG. 28.—*Exochomus contristatus.* (Original.)

The larva has the oval form and spiny appearance of *Chilocorus bivulnerus*, but is handsomely marked with black and white. The spines of the latter become in this species prominent spiny tubercles.

The pupa is not provided with spiny hairs, but is smooth and marbled with black and yellowish brown, in a manner recalling the shell of the tortoise.

In habits this Lady-bird hardly differs from its larger relative, *Chilocorus bivulnerus.* It however shows no preference for the shade, and is found feeding in exposed situations upon the branches infested with Scale-insects, or upon shoots covered with Plant lice. It is exclusively a southern species. In Florida it occurs everywhere upon the Oak, and frequently becomes abundant in the orange grove, where it does good service in ridding the trees of insect pests, devouring the eggs and the young of the larger kinds, and tearing up the scales of Bark-lice in order to feed upon their contents. contents. It is also an active destroyer of the Orange Aphis.

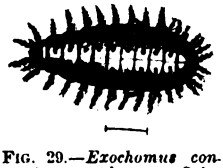

FIG. 29.—*Exochomus contristatus*, larva. (Original.)

THE BLOOD-RED LADY-BIRD (*Cycloneda sanguinea*, Linn.). [Fig. 30, larva; Fig. 31, pupa; Fig. 32, adult beetle, enlarged and natural size.]—

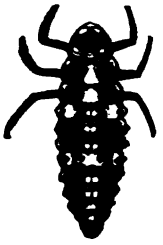

FIG. 30.—*Cycloneda*, larva — enlarged. (After Comstock.)

FIG. 31. — *Cycloneda sanguinea*, pupa—enlarged. (After Comstock.)

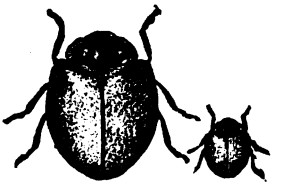

FIG. 32.—*Cycloneda sanguinea* — natural size and enlarged. (After Comstock.)

As its name indicates, the color of this species is orange-red or blood-red, varying somewhat in individuals. The head and thorax are black, each with a pair of yellowish spots; the thorax is also bordered with yellow. Length 5$^{mm}$ ($\frac{2}{10}$ inch). The larva is of a more elongate form than the preceding species; the body not armed with spines, but with rows of small tubercles bearing tufts of short hairs. The colors are bluish-black spotted with orange.

The pupa is orange yellow, clouded and spotted with dusky brown or black.

This is a most common and widely-distributed species, extending even to California, where, however, it is said to be less abundant than in the East. Like most of the species, it is not connected with any particular plant, but is found wherever Plant-lice occur, feeding upon their honey-dew in preference to Bark-lice or other insects, but not seldom attacking the Orange Scale-insects when the Aphis is not at hand. It is a sun-loving species, and is most active and voracious in the hottest weather.

HIPPODAMIA CONVERGENS Guér. (Fig. 33, larva, pupa, and adult; Fig. 34, beetle, enlarged.)—This species is also common from the Atlantic to the Pacific, and everywhere feeds voraciously upon the various species of Aphis and Bark-lice. Its wing-cases are orange-red, with five or six rather small black spots on each, but the remainder of the body is black. The head has a white crown and the thorax is edged with white and has two converging dashes or short lines of white upon the disk.

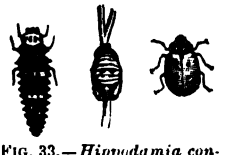

FIG. 33.—*Hippodamia convergens*. (After Riley.)

The pupa is orange-red, of the same shade as the wing-cases of the adult, and has upon its surface a varying number of black spots. The spots are in some individuals entirely wanting, but three spots upon each wing-pad and at least one pair upon the first abdominal joint are very rarely absent. The surface of the pupa is without spines or hairs.

The larva has the same general colors as the perfect beetle, mottled, the brighter red appearing as spots surrounded by areas; the prominences upon the back of each body-joint are with downy hairs; the single pair up of the first three joints forms raised of black color; the head and legs ar

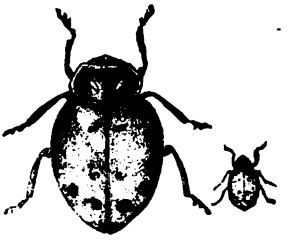

FIG. 34.—*Hippodamia convergens*—natural size and enlarged. (After Comstock.)

The larva of this, as well as that o other species, is attacked by an intern asite which causes its death soon a has become adult. The Lady-bird attaches itself to the plant in the usual to it when about to change int the pupa, however, never appears, l body of the larva becomes rigid and d in shrinking sometimes discloses the outlines of the little ov formed by the parasites within. The number of parasites found body of a single Lady-bird varies from three to six, or even eight. parasite finally issues through a separate hole, eaten in the ski host, and appears as a little four-winged fly of black color a banded wings (Fig. 35). It has been described by Mr. L. O. H

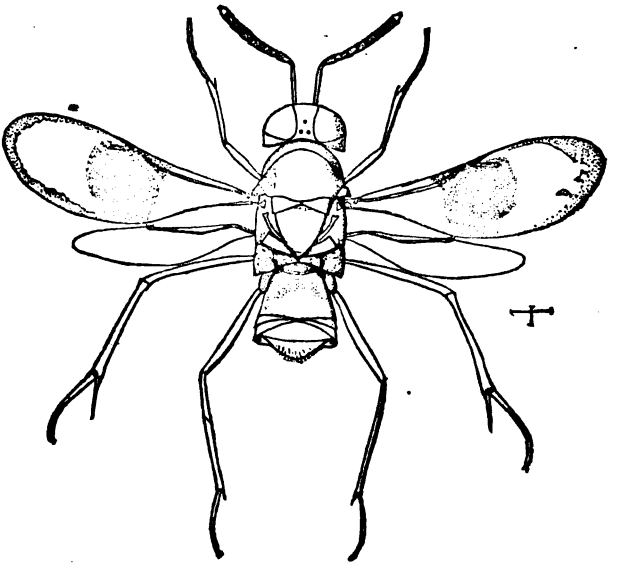

FIG. 35.—*Homalotylus obscurus*. (Original.)

(Bull. 5, Entom. Bureau, United States Department of Agri 1885, p. 22) under the name of *Homalotylus obscurus*. Species same genus are known to attack the larvæ of Lady-birds in Eu

THE SCALE-DEVOURING HYPERASPIDIUS (*Hyperaspidius coccidivorus* Ashmead; Plate V, Fig. 2; *a*, larva; *b*, head of larva much enlarged; *c*, part of side margin of the head, showing antenna and ocelli; *d*, beetle.)—Although on account of its small size this little beetle has been generally overlooked, it is probably the most useful of its family as a destroyer of Bark-lice. It attacks principally the Chaff Scale (*Parlatoria pergandii*), and lives in colonies upon the trunks and branches of orange trees infested with this scale. Both the perfect beetle and its larva busy themselves without ceasing in emptying the scales of their contents, and many instances have been observed of trees ultimately cleared of Chaff Scale through their persistent efforts.

The larva is 1.8$^{mm}$ ($\frac{7}{100}$ inch) in length; body dark purple, covered with minute pubescence having a silver-gray reflection; the head and legs black.

The pupa has the color of the larva, and the form, in outline, of the perfect beetle.

The imago is broadly oval, shining black, with a badly-defined red spot upon each wing-case. Length, 1$^{mm}$ ($\frac{4}{100}$ inch).

The strength of the little insect is apparently not sufficient to penetrate the hard scales of some of the Diaspinæ; it is not often seen to attack either the Long Scale (*M. gloverii*) or the Purple Scale (*M. citricola*), but appears most frequently upon trees infested with Chaff Scale (*P. pergandii*). Even here it does not seem able to bite through the upper shell, but inserts its thin, wedge-shaped head and jaws between the Scale-insect and the bark and eats into it from below. The perfect insect, and to some extent the larva also, devour the young of any species of Bark-louse, but have not been observed to attack Aphis or any other insect.

The young hatch in spring, from eggs laid in patches among the scales.

EPITRAGUS TOMENTOSUS; family *Tenebrionidæ*. (Fig. 36.)—This is about half an inch in length, regularly oval in form, and convex above. The body is dark brown, densely sprinkled with ash-gray pubescence. The habits of the perfect insect are similar to those of the Lady-birds, and it is very commonly found upon orange trees, engaged in feeding upon Scale-insects of all kinds. It tears the scale from the bark and devours the contents, and sometimes the substance of the scales also. Its early history is unknown, but the larva probably lives upon the ground among oak leaves. The beetle is also found abundantly upon scrubby oaks, where it feeds also upon Bark-lice.

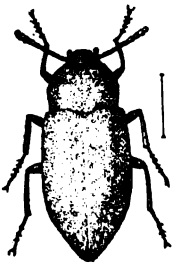

FIG. 36.—*Epitragus tomentosus*. (Original.)

Mulching the trees with oak leaves is very certain to attract these beetles, and they do good service in checking the increase of Scale-insects, although they are seldom present in sufficient numbers to effectually clean the trees.

*PREDATORY LEPIDOPTERA.*

THE COCCID-EATING DAKRUMA (*Dakruma coccidivora* Com.). [Plate VI, Fig. 3: *a*, egg; *b*, larva; *c*, pupa; *d*, moth; *e*, moth resting on a Bark-louse.]—The predatory habits of this little moth were first made known by Professor Comstock (North American Entomologist, I, p. 25), who found its larva eating various species of Bark-lice. It is also very common in the spring of the year on orange trees infested by the soft bodied Coccids, *Lecanium*, *Ceroplastes*, &c., and does incalculable service in clearing them of these pests. It, however, does not attack the Diaspinæ unless compelled by hunger to do so, and seems to experience some difficulty in biting through their hard scales.

Several larvæ live together socially in silken galleries, with which they cover twigs and branches infested with Scale-insects. Underneath the covering of web the caterpillars of Dakruma move back and forth, actively engaged in removing the Bark-lice from the bark and suspending them in the investing web. Nothing could be more thorough than their work. Branches incrusted with Lecanium scales are very quickly cleared of the lice, and the Dakruma larvæ do not cease to extend their operations until every individual Coccid in the colony has been lifted from its place and securely fastened in the web above.

While constructing their galleries the caterpillars stop occasionally to feed upon the Coccids. At such times they seldom finish their repasts, but, like busy workmen, as they are, hastily snatch a bite or two by way of lunch, and suspend the half-devoured fragments in their web. When the entire scale colony has been secured within its net, the Dakruma larva rests from its labors and feeds at leisure upon the Coccids suspended in its larder. It devours not only the eggs and young and the softer parts of the Bark-lice, but even to some extent their harder skin or scale. The result of its operations upon Lecanium and Ceroplastes scales is to utterly annihilate the colonies of these insects which they attack.

*Larva.*—A rather slender caterpillar, nearly half an inch in length, very dark green, almost black in color; the body bears a few long hairs arising from pale brown spots.

*Pupa.*—The chrysalis is formed within the galleries of the larva, and is loosely wrapped in a cocoon of silk. It is slender, tapering to the anal extremity, of varying shades of brown, darkest on the back and lighter on the belly and wing-pads.

*Imago.*—A small, dark-colored moth, one-third of an inch in length. The body is dark-brown above and gray beneath; the forewings are light gray, with markings of brown and black; the eyes are black and distinctly faceted.

*Egg.*—White, oval, the surface covered with a network of raised lines, the meshes forming irregular hexagons.

*History.*—The eggs are laid singly among the Coccids; they hatch in five or six days; the caterpillars, if food is abundant, attain their full

wth in ten or twelve days; their pupa stage lasts about the same gth of time, unless belated in June or July, in which case they re- in in pupa until the heat moderates in August or September. The erpillars are first seen in March, but are not common until April or y. The moths are most abundant in June, but disappear in mid- mmer and appear again in the fall. There are at least two, and pos- ly three, broods in the spring and early summer, and one in the fall. e pupæ and a few belated larvæ may be found in winter at any time.

HE PALE DAKRUMA (*D. pallida* Comstock).—Another species, closely embling the preceding and having similar habits, is described by ofessor Comstock (Rept. Comm. Agric. for 1879, p. 243) from gall-like cids on Oak. From its similarity of habit this species may be ex- ted to feed upon Orange Scale-insects, although it has not been actu- observed to do so. It is known from the first species by its lighter r in both the adult and larval stages.

CALE-EATING TINEID.[2] (Fig. 37.)—The caterpillars of a Tineid moth habits very similar to Dakruma, are found eating various Coc- , and have also been observed to feed the common Long and Chaff Scales Orange. Several specimens of the were bred in winter from larvæ biting tightly-rolled dead leaves in- d in the webs of a social leaf-eating pillar (*Anæglis*). The leaves thus ied had been infested by Scale-insects, and the scales within the t of the larvæ were all gnawed and partially devoured.

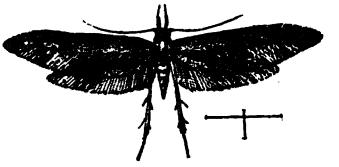

FIG. 37.—*Scale-eating Tineid.* (Original.)

summer the same species is found forming silken galleries like of Dakruma upon orange branches infested with Diaspinous scales. following observations of the habits were made upon several placed upon a twig of Orange covered with Long Scale (*Mytilas- oreriі*). The larvæ began at once to make a tangle of web in a fork e twig, which was afterwards extended into a gallery along the h. From time to time a larva reached out and tore a scale from ark. Sometimes it devoured the whole scale, with the contained t; again it turned the scale over and ate the contents, eggs and er Coccid, retreating finally to its gallery and taking with it the y shell, which it fastened in its web. Occasionally the caterpillars hed from the bark and fastened in their web scales with their liv- ontents untouched.* From the frequent additions made to it, the t of the caterpillars soon became entirely coated with fragments, ould with difficulty be distinguished from the surrounding bark.

e contents of these scales were, however, sooner or later devoured. The larvæ equently gnawed into a scale at one end and pulled out and devoured the in- aving the empty scale still attached to the bark. They also ate sparingly the y exudations of the bark.

These fragments consisted in great part of half-eaten scales, from which the eggs and the Coccids had been extracted.

*Larva.*—The caterpillars are about one-fourth inch long, dark purple in color, with lines of lighter color in fine blotches along the sides.

*Pupa.*—The chrysalis is sometimes formed upon the branches within a cocoon of silk densely covered with scales, and sometimes concealed in a dead, rolled leaf, or otherwise protected under fragments lodged in spider-webs, &c. It is dark brown in color, and of the usual form, without striking peculiarities.

*Imago.*—The moth is less than one-third inch in length, with rather long wings; head and thorax are ashen gray; the upper wings are lustrous lead color, with silvery scales intermixed; they are marked each with a single distinct black spot near the base and a pair of faint dots near the tip. The under wings are silvery gray, with the membrane showing iridescent blue between the scales in the middle of the wing; the antenna in one sex has the third joint thickened and curiously excised, the excavation covered with a tuft of long scales.

*History.*—The larvæ of this species have been observed only in the fall and winter months, and the number of broods is not known. It may be assumed to have three or four broods. Moths appeared in thirteen or fourteen days from pupæ formed late in September. In December and January they remained twenty days in pupa.

Two other moths of this family (*Tineidæ*) have been noted* as feeding upon Coccids in Florida, but they were bred only from gall-like Bark-lice found upon Oak, and never occurring upon orange trees.

### *INSECTS OF THE ORDER HEMIPTERA.*

THE SPIDER-LEGGED SOLDIER-BUG (*Leptocorisa tipuloides*, Latr.; Plate VI, Fig. 4.)—This is a slender, long-legged bug. The color of the body is orange-yellow, with a rounded spot of black upon the thorax; the legs, antennæ, and tip of the beak are black; the wings in the adult have a band of black across the middle and an oval spot of black covering the terminal half; the legs are covered with almost invisible, short, stiff hairs, which cause small light objects to adhere to them. The bodies of the young especially are covered with fragments, consisting in great part of the pellicles of insects which have been emptied of their contents by the bug. Length of the adult, $\frac{7}{10}$ inch.

The habits of this bug are sluggish, but it flies readily when adult. It is found, often in great numbers, upon the Orange and other plants when they are infested with the common Lecanium Scale (*Lecanium hesperidum*, Linn.). The bug sucks the juices of these soft-shelled Bark-lice, but has never been observed to puncture the hard scales of the Diaspinæ. Unfortunately the Leptocorisa does not discriminate between friends and foes, but destroys many predatory and useful insects.

* Rept. Comm. Agric. for 1879, p. 244.

It has been observed to capture and suck the juices of ants and of the larvæ of the Lace-wing flies, and also to empty of their contents the eggs of other insects.

*Eggs.*—The eggs are long, vial-shaped objects, brick-red in color; they are deposited upright, in small masses, aglutinated with a viscid, frothy substance, which dries very slowly and remains sticky long after the eggs have hatched. The eggs hatch in about one week after they are deposited.

*Life-history.*—The number of broods is indefinite; solitary individuals are found at all seasons, but become more numerous in spring and fall, upon plants infested with Lecanium Scale, which also breeds most rapidly at these seasons. The young suck the juices of plants for a short time after hatching, but afterward feed exclusively upon insects. They change their skins frequently, gradually acquiring fully-developed wings and other characters of the adult; the process occupying, according to the season and temperature, from three weeks to two months. This species is much more gregarious in its habits than most predatory Soldier-bugs. Not only the young, but also the adult insects are frequently found in large colonies.

*Parasite.*—The only enemy known to attack this bug is a minute Proctotrupid fly, belonging to the genus *Telenomus*,[3] which is bred within, and destroys its eggs. The parasite is black, with yellow legs. A single fly issues from each egg of the bug, leaving a round hole eaten in the side of the shell.

Two small bugs (*Hemiptera*) prey upon the Mealy-bug (*Dactylopius destructor*). Specimens of the young bugs were sent to the Department of Agriculture, from Florida, on leaves of Orange infested with Mealy-bugs, and were observed to suck the eggs and young lice of the Mealy-bug.

In the young of one species the color is deep red, with brown eyes; antennæ and legs pale reddish or yellowish white, with the thighs slightly dusky; the antennæ four-jointed, the fourth joint longest; the proboscis short, rather stout; from each side of the abdomen, near the tip, projects a pair of long bristles. Length, when adult, about $3^{mm}$ ($\frac{12}{100}$ inch).

The other species is a smaller insect than the preceding. The young bugs are coral-red, the shanks and tips of the legs white, the antennæ also parti-colored, having the third joint and tip of the terminal (fourth) joint white; the proboscis is white, and reaches beyond the middle of the body; the body and members are covered with short, pale hairs. The adult is purple-brown, with lighter eyes, and has parti-colored legs and antennæ; the wings are ornamented with a large chocolate-brown spot edged with white or pale red, and situate at the base of the membranous portion, near the tip of each wing-cover; the body and surface of the wings is thinly covered with silvery hairs, giving a hoary appearance to the insect. Length $2.2^{mm}$ ($\frac{8}{100}$ inch). The egg is long and slender, vase-shaped, pearly white, with a tinge of pink, and has a white rim; it is

deposited singly, lying upon its side, in any situation where the female may find a lurking place.[4]

This little bug is one of a number of insects often associated with the Orange Web-worm, *Anæglis demissalis*. (See Chapter X.)

## *INSECTS OF THE ORDER NEUROPTERA.*

### LACE-WINGS.

CHRYSOPA. (Fig. 38, adult fly and eggs of *Chrysopa oculata*.)—There may frequently be seen, moving rapidly about upon the trunk and branches of the orange tree, little flocculent masses, grayish in color, nearly hemispherical, and of about the size of a split pea. When one of these mossy bunches is examined closely it is found to be an insect, whose back is covered with a nondescript collection of fragments, consisting chiefly of the dried skins and broken remains of insects. This is the young of a Chrysopa, or Lace-wing fly, and the covering with which its soft body is protected, and which renders it less conspicuous upon the bark, is formed from the accumulated remains of the victims whose juices have served the animal for food.

FIG. 38.—*Chrysopa oculata.*

The Lace-wing feeds to a great extent upon Bark-lice, tearing loose the scales from the bark, and after devouring the soft contents adding a portion of the *débris* to the load upon its back. Plant lice and many other small insects are also eaten. The activity and rapacity of the larva is remarkable; it wanders restlessly over all parts of the tree in search of food, and although insignificant as to numbers in comparison with the swarming millions of its prey, it yet exercises an appreciable influence in holding them in check.

*Larva.*—The body of the larva, divested of its extraneous covering, is somewhat broadly oval, divided into joints, from the sides of which arise branching spines. These spines serve to hold in place the loose, dry materials which are piled upon its back. The legs are quite long and slender, adapted to rapid movements, and the jaws are sickle-shaped, long and keenly pointed, projecting beyond the ambuscade under which the insect moves.

*Pupa.*—When prepared to pupate, the larva forms an almost globular cocoon by drawing together with strands of silk the loose materials it bears upon its back, and constructing beneath it a spherical cell of thin but strong parchment, pure white in color. Within this the pupa lies curved like an embryo. The pupa has the form of the perfect insect, barely masked by a transparent envelope, and with the wings and other members contracted and closely applied to the body. It gradually changes in color from white to pale green, and finally issues by pushing outward a circular cap which forms one end of its cell.

*Imago.*—The perfect insect is a four-winged fly, of a delicate pea-green color; eyes a resplendent copper bronze. The wings are large, closely veined, hyaline with a violet reflection; when at rest they meet in a

ridge like the peak of a roof. The antennæ are black, paler outwards. Head porcelain-white; the enlarged first joint of the antennæ, and also a triangular spot on the head at the base of each antenna purple red; a band of the same color on each side of the thorax.

*Eggs.*—The eggs are laid upon various parts of the tree, often near a colony of Plant-lice, in groups of five to fifteen, each supported on the end of an erect, bristle-like stalk, about 0.4 inch in length. The object of this device is said to be the preservation of the egg from the young of its own kind, for such is the rapacity of the larva that those first hatched would immediately devour the remaining eggs if they were deposited within reach upon the surface of the plant.

*Life-history.*—The development of Chrysopa is quite rapid in hot weather, and is greatly retarded by cold. There are apparently but two broods each year, in spring and fall. Eggs are seen as late as the middle of July, but the larvæ only are abundant in midsummer. In winter both larvæ and eggs are found, but the perfect insect is not common except in early summer and late in the fall. There are said to be several species of Chrysopa frequenting the Orange, which, however, are with difficulty distinguished from each other, and have identical habits. One of these has been described as new by Ashmead under the name *Chrysopa citri*.

*Parasites* (*Perilitus* sp.).[5]—A four-winged parasite destroys the Chrysopa, and issues from its cocoon. It is of slender form, with the abdomen stalked; color beneath light yellow, above black, with yellow markings; the legs yellow, the antennæ dark, the face yellow; eyes, vertex, and back of the head black; the rings of the hind-body are alternately black and yellow. Length, 3$^{mm}$ ($\frac{12}{100}$ inch).

HEMEROBIUS.—Several species of this genus, which is closely allied to Chrysopa, exist upon orange trees and feed upon the young of Bark-lice, and to a still greater extent upon Plant-lice (*Aphis*). They have nearly the same habits as Chrysopa, but the larvæ do not protect themselves with a covering of fragments. The larvæ are mottled with gray, brown, and dull red, and are more slender than those of the preceding species.

The pupa is formed in a globular cocoon of white parchment, not covered with fragments.

The perfect insect is much smaller than Chrysopa; the wings are less transparent, and are covered with down of light-brown color.

### *MITES—ACARINA.*

Next to their internal parasites, Mites constitute the most important enemies of Scale-insects, and exert a constant and very powerful influence in checking their increase. They are at all times present wherever Scale-insects exist, and in numbers limited only by the food supply. They cannot penetrate the hardened shells of mature Scale-insects, but

they destroy great numbers of the young lice, as soon as the latter have fastened themselves to the bark, and while their scales are still soft and thin. They also creep into the open end of scales which have begun to hatch, and destroy a portion of the eggs. The scales vacated by parasites, in which have been left convenient open doorways, furnish the Mites with secure retreats and places of deposit for their eggs. Usually the dry and distended skin of the Coccid is left by the parasite, nearly filling the scale, and with a minute exit hole immediately opposite that in the outer shell. Thus the Mites or their young and eggs are provided with a double envelope separated by layers of confined air, and nearly impervious to liquids. It is, therefore, not astonishing that applications sufficiently penetrating to kill Scale-insects do not reach the Mites and their eggs thus protected. In fact the latter very frequently increase enormously after an effective application, because the loosening of the scales by the wash enables them to penetrate to and feed upon the dead or dying Bark-lice, and the supply of food is for a time largely increased.

To cause a marked increase in the number of the Mites, it is sometimes sufficient to loosen the scales here and there upon the trunk and branches which are most thickly encrusted with them, by scraping the bark with a stick or knife blade. This gives the Mites an increased supply of food, and stimulates them to active breeding. The result is often to effectively check the progress of the Scale-insects for the time being, although they cannot be exterminated in this way. The method is not advanced as a practicable remedy, and cannot be made to replace the proper application of insecticides, but from its simplicity it is frequently useful as a means of gaining time, when remedies are not at hand.

GLOVER'S ORANGE MITE (*Tyroglyphus ? gloverii* Ashmead). [Plate VI, Fig. 5.]—This is the commonest species found among Orange Scale-insects; it is also the smallest species and the most active and rapid in its movements; it is somewhat longer than broad, slightly flattened; in color it varies from pure white to yellowish, and often a pale pink or flesh-color. This color-variation is due to the varying nature of its intestinal contents, seen through the semi-transparent body. Length about $0.1^{mm}$ ($\frac{4}{100}$ inch).*

The eggs are white, and are deposited either singly or in small groups, under a tangle of spider's web, among dead scales, &c.; lurking places in which the white, six-legged young congregate and undergo their transformations.

* The form in most soft-bodied Acarina is very changeable, depending upon the condition of the animal, whether full-fed, or depleted by fasting. The figure of this species on Plate VI represents the shape commonly seen. When emaciated, the sides of the body become deeply sinuate or lobed, deep pits are formed upon the upper surface in front, and several transverse folds in the skin appear to divide the abdominal portion into segments. In plethoric individuals, the distention of the body into an oval sack obliterates every trace of fold or depression upon its surface.

This species certainly feeds upon the eggs of Coccids, and probably also upon their young, and sucks the juices of the adult Bark-lice, whenever it can get at them.

THE HAIRY ORANGE MITE.[6]—Probably the next in point of abundance is a larger mite, dark red in color, covered with pale hairs, broadly oval in form, and with several irregular indentations upon the back. This mite is also very rapid in its movements, and is certainly predatory upon Scale-insects or their eggs.

The eggs are sherry-brown in color, quite large and globular, and are usually deposited singly upon the leaf among scales, or strung like amber beads upon strands of spider's web, which harbor the mites and their young.

The six-legged young are spindle-shaped, of a lighter, ruby-red color, the extremities pale, and have an eye-like prominence on each side of the anterior body. The length of the adult is 0.3$^{mm}$ ($\frac{12}{1000}$ inch).

THE SPEAR-HEAD MITE.[7]—Another not uncommon Red Mite seems to be predatory upon Scale-insects. It is rather larger than the preceding; dull, opaque red, not hairy; the body is distinctly diamond or spear shaped, somewhat flattened, with a sharp median ridge upon the back, having on each side a longitudinal depression; a band of pale brown is sometimes seen across the middle of the back. Length, 0.35$^{mm}$ ($\frac{14}{1000}$ inch).

This species is sluggish and solitary. The eggs are deep red, globular, and are deposited singly among scales.

There are numerous species of Mites found about and among Scale-insects, of which a few only appear to be dependent upon them for their subsistence, or peculiar to the orange tree and its kind. Some of these mites are undoubtedly merely scavengers, living about, if not upon, the dirt and *débris* that collect where the plant is fouled with Scale-insects, but never appearing to attack the insect itself in any stage. Possibly they feed upon the excrement or excretions of other insects, or upon molds that accompany such ejected matter.

The predatory Mites are usually active, running hither and thither restlessly, occasionally stopping to examine the sealed edge of a scale or to pry into a vacant and deserted shell.

The young of Mites frequently differ entirely from the adults in form and coloration; they have, moreover, but three pairs of legs, while the adults have four pairs. The life-history of many species is imperfectly known.

THE SPOTTED MITE.[8]—This is a rather large, egg-shaped or pear-shaped Mite, with a very plump, smooth, shining, and pellucid body, either white or honey-yellow in color, and provided with a few very long and fine bristle-hairs; the division of the body into two parts is barely indicated by a fine line; in adult specimens the body behind is more or less clouded with red-brown, forming sometimes a distinct spot; a large round spot on each side, upon the declivities of the hind-body,

varies in color with the age and condition of the individual, from sulphur-yellow to brick-red and dull brown. Length, 0.38mm ($\frac{15}{1000}$ inch).

The Mite is slow in movement, and gregarious. White, elongate eggs, and the six-legged young are found in groups of three or four to twenty upon scale-infested orange leaves.

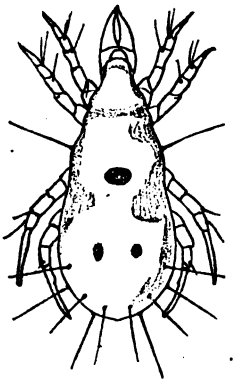

FIG. 39.—*Orange Mite.* (Original.)

While this Mite may with some probability be considered a scavenger, feeding upon dead vegetable and animal matter, it is almost certain that it does also suck the eggs of Scale-insects, with which it is very closely associated.

A species of *Rhizoglyphus* (?),[9] similar to but distinct from the preceding, was sent by Professor Comstock from Florida. It was found in all stages from egg to adult on orange leaves infested with the Long Scale and the Common Mealy-bug. Fig. 39 represents the mite, after a drawing by Mr. Th. Pergande; the following are his notes upon the species: "These Mites were especially numerous around the Mealy-bugs, and they were noticed to suck and destroy the eggs of that insect; the eggs of the Mite were deposited between the egg-masses of the Louse and also on the leaf itself; the eggs are white, perfectly oval; the Mites are white, almost transparent, the full-grown ones slightly yellow, with one or sometimes three pale brownish spots; when there is only one spot it is generally situated on the posterior portion of the abdomen, but when there are three spots they are arranged as shown in the figure—the front one is largest and the two posterior spots are small and rather indis-tinct. The male is shorter and stouter than the female."

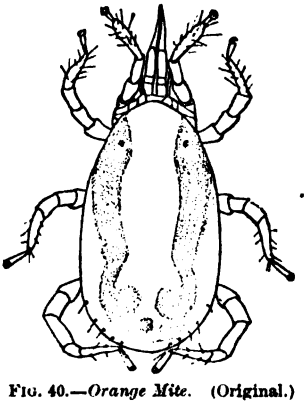

FIG. 40.—*Orange Mite.* (Original.)

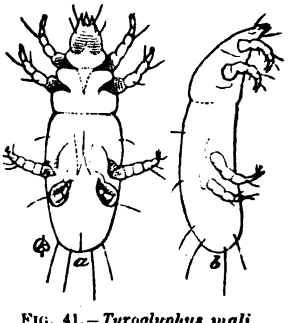

FIG. 41.—*Tyroglyphus mali.* (After Riley.)

Associated with the foregoing is a Mite [Fig. 40] with a more flattened form, concerning which the following notes are given, with the figure here produced:[10]

"A single specimen of a second species of Mite was also found on an orange leaf sent by Professor Comstock, from Sanford, Fla. This Mite is quite different from the preceding; it is smaller, more yellow, and there are small and very distinct eyes; the legs, especially the first pair, are quite differently formed. It is not as hairy and not as slender as the

species. This Mite also evidently preys either on the Mytilaspis
Dactylopius."

ery long-bodied Mite, without spots, is found occasionally in empty
aspis scales; it has the same habits as the Spotted Mite. This
s may be identical with *Tyroglyphus malus* Shimer, which preys
the Oyster-shell Bark-louse of the Apple. The figures of the lat-
om Riley's Fifth Missouri Report, are here reproduced. [Fig. 41.]

E ORBICULAR MITE.—This is the largest Mite found among Scale-
s; it is nearly circular, or slightly oval, in outline; the body is
and somewhat flattened, covered with a pol-
, horny shell of brown color, surmounted by
fine bristles. The shell or carapace is turned
at the sides and ends, so that the short,
legs are concealed beneath it as the animal
, and only the tip of the head and beak pro-
beyond the front margin. Length, about
($\frac{1}{100}$ inch).

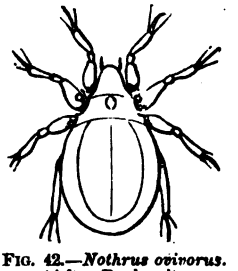

FIG. 42.—*Nothrus ovivorus*. (After Packard).

s is an active, wandering Mite, undoubtedly
tory upon Scale-insects, but found also suck-
ie eggs of many other insects. Its eggs are
and transformations undergone, under loose bark and in crevices,
the early forms are mingled with those of numerous other Mites,
which they have not been clearly distinguished.*

ariety of other Mites are found from time to time wandering over
infested leaves and branches, but the forms above indicated are
ed to include those most closely connected with orange pests.

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s may be the *Nothrus ovivorus* of Packard, Fig. 42, which is found sucking the
the Canker-worm.

# CHAPTER VII.

## MEANS OF DEFENSE AGAINST SCALE-INSECTS—REMEDIES.

### INTRODUCTION OF SCALE-INSECTS ON IMPORTED PLANTS.

In the wide range of insect life few forms possess a greater vitality than is found among the Bark-lice, and none are more readily transported upon plants from place to place, and from one country to another. Whenever orange plants are imported from infested districts, Scale-insects will be brought with them, and their introduction and spread in regions where they were before unknown are inevitable.

Even the soft and unprotected Coccinæ sustain without injury an astonishing amount of rough handling, and exist for long periods of time without food or moisture.

During the winter of 1882–'83 living specimens of the Common Mealy-bug (*Dactylopius adonidum*, Linn.) were sent to the writer, through the mails, from Italy and also from Morocco, inclosed with a few orange leaves in common letter envelopes. Although the orange leaves were entirely dry, and some of the insects were crushed between their surfaces, many, even of the adults, were found to be uninjured, and young lice had even been produced in transit.

The scale-covered Diaspinæ, it may well be supposed, are even better able to sustain long voyages than their soft-bodied relatives, and their eggs are not affected by long-continued drought, nor by sudden changes of temperature.

It can hardly be doubted that all the common Bark-lice found upon the Orange in Europe have been many times imported into Florida upon living plants. In this way, in the year 1835, it is supposed, the common Long Scale (*Mytilaspis gloverii*) was introduced, first at Jacksonville, and subsequently at Saint Augustine, from whence it spread devastation over all the groves then in the State.

In 1855, according to Glover, a new scale, probably the Chaff Scale (*Parlatoria pergandii*), was introduced into Florida on some lemons sent from Bermuda. More recently a new and very destructive scale has made its appearance at Orlando, in Orange County, Florida, and is slowly but surely spreading to other parts of the State. This is the Red Scale of Florida (*Aspidiotus* [*Chrysomphalus*] *ficus* Ashmead). It was first observed in a grove near Orlando, in the spring of 1879, upon a sour-orange tree brought from Havana, Cuba, in 1874. Professor

Comstock received specimens from Havana, and learned that it was a very common pest in the public gardens of that city.

In California, owing to the very direct communication with China and Japan, and frequent importations of plants from these countries, many destructive species of Bark-lice have been introduced upon fruit and shade trees. Some of these are the most serious pests of their kind; many have a wide range of food-plants, including also the Orange, and one at least, the Red Scale of California, is peculiar to citrus plants. It was introduced into California from Australia. Professor Comstock believes this to be the most destructive species known to infest citrus plants in this country. Its introduction into Florida, together with others now ravaging the groves of California, is greatly to be feared, and is probably only a question of time, as the interchange of plants between these two States increases annually.

Not only plants of the citrus family, but many other trees and shrubs, and notably the Olive, may cause the introduction of Scale-insects, some of which have, besides the Orange and its kind, a great variety of food-plants.

It would be well for the horticultural interests of Florida if some system of inspection of imported fruit-trees could be adopted and vigorously enforced by the State. This would, no doubt, be difficult of accomplishment, and, perhaps, impracticable. Individual importers should, however, be made fully aware of the danger which exists of introducing other destroyers more serious than those already at hand, and should be on their guard. Living plants received from foreign countries ought to be carefully cleaned upon their arrival, and all insects found upon them destroyed.

It is not easy to estimate the extent of the damage that would be occasioned should any of the Aspidiotus scales now ravaging the groves and orchards of California be permitted to obtain a permanent foothold in Florida.

## PRECAUTIONARY MEASURES.

*Infection from nursery Stock.*—What has been said as to the danger of introducing exotic Scale-insects by importations from abroad will apply as well to the spreading of domestic species by the exchange and sale of nursery stock.

It must be acknowledged that many of the leading nurserymen are fully alive to the necessity of establishing and maintaining a reputation for painstaking care, and rarely send out infested plants. Others exercise less care and frequently scatter insect pests by means of the befouled plants they distribute.

Close planting in the nursery is a most frequent cause of the appearance of Scale-insects in destructive numbers. Young orange trees are planted a few inches apart in rows, and are often left for years in close ranks, with their branches interlocking, and affording easy passage for

the migrating young of Bark-lice, so that if they effect a lodgment upon any plant, the entire row, and even the whole nursery, is quickly overrun by them.

The crowding of the plants prevents free and vigorous growth; they are stunted, and for want of nourishment, as well as lack of light and air, they are thrown into a condition in which they are particularly liable to the attack of Scale-insect. In common parlance, "they breed scale."

In the existing almost universal distribution of the pest, those nurseries only can be kept from becoming foul in which a reasonable amount of space is allowed to each plant for its growth and cultivation. At least 18 inches should intervene between the plants, and the rows should be not less than 3 feet apart. Experience teaches that it is easier to keep clean and uninfested a large, well-ordered nursery than it is to remove the Scale-insect from a single orange tree of moderate size when once the pest has become fully established.

No part of the grove is so liable to suffer neglect as the nursery, and it is unfortunately a very common practice to allow seedling plants to grow up without attention in neglected corners, and frequently to become so foul with scale as to become a source of infection to the groves and nurseries in the vicinity.

To this neglect, undoubtedly, is due the fact that the advance of insect pests has fully kept pace with that of the orange industry in the recently occupied districts, both in Florida and California.

*Protection afforded by Hedges and Forest Trees.*—It is a serious evil, and one as yet hardly appreciated, that in Florida, in removing the forest to make way for the advancing orange groves, every tree is generally sacrificed. Not even in the lanes and roadways has the ax spared an occasional pine to serve as a wind-break against the sweep of storms. In many districts, once well clothed with timber, the naked land for many miles now lies exposed to the destructive force of gales, which, by whipping and thorning the fruit, will, when the groves begin to bear, occasion severe losses.

The pines of the original forest, from their great height, serve to break the force of upper currents, and a single giant tree extends its protecting influence over a wide area. If cut, the loss is well-nigh irreparable; many generations must elapse before its place can be satisfactorily supplied by the lower and more spreading oaks and pines of second growth. But a discussion of this subject, though of sufficient importance to horticulturists, would be out of place in the present treatise, were it not for the great value of wind-breaks as an aid in isolating and preventing the spread of Scale-insects and other pests of fruit-trees.

From the time of their first appearance it has been remarked that Scale-insects spread most rapidly in the direction of prevailing winds. This phenomenon is now known to be due to the influence of the wind in guiding the flight of other insects which transport the minute, crawling young of Bark-lice upon their bodies.

The feet and tail-feathers of birds are also invaded by the crawling lice, which are thus borne with them in their flights to be scattered over new plantations.

The leaves and branches of shrubs and trees standing to the windward of a grove protect it by receiving these pest-laden visitors, and detaining them long enough to relieve them of the scale-larvæ they bear upon their bodies.

It is, therefore, a great protection to leave narrow belts of timber between adjoining groves, allowing the undergrowth to spring up and form a natural screen, or else to replace this with cultivated plants. Fences may usefully be replaced by thorny hedges, which will aid in maintaining an effective quarantine against invasions of Scale-insect and other minute pests.

To be of value the screen or hedge should, of course, be composed of such plants as are not themselves subject to the attacks of orange insects; otherwise it may first become infested and afterward prove a source of danger, in place of a safeguard. For example, the Oleander is not desirable in the neighborhood of orange trees, because of its liability to the attacks of certain soft Scale-insects (*Lecanium.*) On the other hand, pines, cedars, and other coniferous plants, having very few insect enemies in common with other plants, are absolutely safe, and are also admirably adapted to form wind-breaks.

## CLEANLINESS.

*Beneficial action of Light.*—It is with plants as with animals, a rule to be borne in mind that foulness breeds vermin. The growing bark as well as the leaves has its pores and its respiratory functions, for the proper performance of which it needs exposure to light and air. From the lack of these conditions for healthful growth, the inside branches of orange trees dwindle and lose vitality, becoming breeders of Scale-insects, which thrive best when the plant has lost its vigor.

*Pruning and opening Tops to Light and Air.*—Upon trees of considerable size and which have formed dense heads, Bark-lice usually make a start upon the devitalized inside branches, and from thence they may spread over a portion or the whole of the tops.

It may be doubted if any bearing orange tree entirely free from scale can be found in Florida. Somewhere under the canopy of leaves there will always be a twig or stifled branch upon which the enemy lurks in concealment, latent, but ever present, and waiting for favorable conditions to swarm forth in destructive numbers and possess the tree. The careful cultivator needs not to be warned of this source of danger, and will not allow dead and dying branches to remain and accumulate until they become a menace to the health of the tree and breeders of insect pests. He will frequently examine his bearing trees, and at least once each year remove the unfruitful and devitalized inside growth from their tops.

*Clearing off Webs.*—Young trees, while they require less pruning than the old, will well repay the time and care that may be expended in keeping them free from entangling moss and from the webs of insects. These not only befoul and injure the trees, but directly foster Scale-insects by sheltering and protecting them from the attacks of many very active enemies and parasites. The webs and lairs of spiders in particular may be regarded with suspicion, and will very frequently be found to harbor the foe when it can be found nowhere else.

*Scrubbing the Trunks.*—Accumulations of Scale-insect, living or dead, as well as of lichens and other fungi, upon their trunks affect most injuriously the health of trees, and their removal from the bark always causes a marked improvement in condition. The incrustations upon orange trees formed by Chaff Scale are particularly hurtful. This species continues to accumulate for many generations, piling its scales over each other as long as it is possible for the young to find a crevice through which to insert their sucking beaks. There results a dense crust, which remains for years, and becomes still further consolidated and converted into a tough, fibrous coating by the threads of the peculiar fungus, which, as has already been mentioned, feeds upon the *débris* of this Bark-louse.

To partially cleanse the trunks of orange trees, without entirely destroying the life that always remains in scale-crusts, no matter of how long standing, is to expose the plant to fresh incursions of Scale-insects by clearing away the obstructions to their spread. Therefore it is important not only that the clearing should not be neglected, but that, when undertaken, the work should be thorougly done.

For scrubbing the trunks properly a brush stiff enough to remove the scales is required, and to insure the destruction of any insects or eggs that may escape, hidden in unseen crevices, it should be dipped in cleansing liquids, such as the dilute kerosene and soap emulsions recommended in the following pages for spraying the trees, or very strong solutions of lye may be used, and will be more effectual in destroying fungi than the kerosene washes. Solutions of whale-oil soaps are very commonly employed and with good effect; but if the solutions are thick and strong, as indeed they need to be in order to kill the insects, the trunks should be rubbed down before they dry with clear water, to remove the film of soap, for this, if allowed to remain, has a tendency to harden the bark by clogging its pores.

*Palmetto Brushes.*—A better implement than the common domestic scrubbing-brush, usually employed in cleaning tree-trunks, may be made in a few moments out of a bit of saw-palmetto root (root-stalk) by pounding the ends until the fibers separate and form a brush. For the removal of scales and dead bark nothing better than this rude brush can be devised. In Florida the material is always at hand and costs nothing. In use the palmetto brush wears away slowly, but never wears out so long as any portion of it remains.

POPULAR METHODS AND REMEDIES.

*Cutting back infested Trees.*—The utter inadequacy of nearly all the washes hitherto used has led many fruit-growers to despair of obtaining permanent benefit from the application of remedies, and a common practice has been to cut back badly infested trees, leaving only the main trunks, or in the case of well-grown trees, a portion of the main branches, and to scrub thoroughly every part of these with solutions of soap or lye, using a stiff brush, and as far as possible removing every scale. This, however, involves great care and considerable labor, and the complete extermination of the pest is rarely accomplished in this way. The loss of branches is indeed replaced with extraordinary rapidity, but the Scale-insects reappear as if by magic, and in one or two years become as bad as before.

*Fumigating.*—Various plans have been proposed for destroying Scale-insects with pungent vapors of various kinds. The difficulties in the way of applying vapors to trees growing in the open air are very great, and appear to have been overlooked by the advocates of this method. Tobacco smoke has been very frequently tried in inclosed green-houses, but although it will destroy Plant-lice (Aphis), it is found to have no effect upon Scale-insects, which are far too well protected by their tightly sealed scales to be reached by vapors, except those of a corrosive nature.

Sulphur has been recommended, evidently on theoretical grounds only, as its fumes are not less destructive to vegetable than to animal life. The chlorophyl of the leaves and plants is bleached and the life of a plant destroyed by a short exposure to any gas containing sulphur. Actual trial of fumigation upon the Orange was made by covering a young and vigorous plant with a barrel and exposing it for ten minutes to the fumes produced by burning one ounce weight of sulphur. The leaves were completely bleached and the plant killed. The Scale-insects upon it (Long Scale) were uninjured by the sulphur vapor, and survived until the bark became entirely dead and dry, perishing finally from want of food and moisture.

*Applications to the Roots.*—No results of any value have been attained by attempts to kill Scale-insects through the juices of the plant by making applications to the soil with the expectation that they will be taken up by the roots. Many nostrums are advertised and sold as insecticides, which it is claimed act in this way. There are also in the market not a few combined fertilizers and insect-exterminators, so-called, to which is assigned a double action, beneficial in the case of the plant, but deadly to the insect life which it supports. These claims are based upon the assumed power of the plant to appropriate and mingle with its juices unchanged the substances which have insecticide properties—an assumption wholly at variance with the known laws of vegetable physiology. In fact an insecticide, if it could be introduced into

the circulation through the roots of the plant, would be far more likely to injure the plant itself than the Bark-lice upon it.

*Inoculating with Poisons.*—For the same reason it has been found impossible to reach and destroy insect pests by inoculating the bark or wood of the trunk or branches.

The attempt has usually been made by boring into the trunk of the tree, introducing the article to be tested, and tightly closing the hole with a plug. Numerous experiments of this sort are recorded. Of the long list of substances which have been thus tried, and which includes many mineral and vegetable poisons, as well as sulphur and other substances possessing insecticide properties, none have proved effective.

*Popular Fallacies.*—There is a widespread and apparently well-founded opinion that vigorous trees are in little danger from attacks of Scale-insects, but if from any cause a tree becomes enfeebled, its investment is only a question of time. Many persons therefore reject the aid of insecticides, and when a tree becomes infested, rely upon a liberal use of fertilizers to restore its lost vitality and force it into vigorous growth, believing that in this way it will rid itself of the pest. It cannot be denied that this course of treatment is often successful, at least for a time, but the Scale-insect is never entirely eradicated, and its return at some future time may be expected. Indeed, overstimulation by means of fertilizers is apt to defeat its object, and reaction follows in unfavorable seasons.

In fighting Scale with fertilizers, therefore, success may be said to depend upon conditions unknown or beyond our control. When these are favorable, the system may be found to work well; otherwise failure is inevitable, and by adhering to it valuable time will be lost, and the pest will perhaps be allowed to spread until it can with difficulty be controlled.

## EFFECTIVE REMEDIES.

*Kerosene.*—This is without doubt the most effective insecticide for use against Scale-insects, and it is almost the only substance known which will with certainty kill their eggs without at the same time destroying the plant. The difficulty of diluting it, and the danger to the plant of applying it undiluted, have long prevented its extensive use. Easy methods of emulsifying the oil and rendering it miscible with water are now known, and have recently been set forth by Professor Riley in his official reports.

*Milk and Kerosene Emulsions.*—The method of emulsifying kerosene with milk, as given in a preliminary report on Scale-insects in the Report of the Commissioner for the years 1881 and 1882, remains the best and simplest, where milk can be easily and cheaply obtained. The milk should first be heated nearly to the boiling point, and then mixed with kerosene in the proportions one part of milk to two parts

rosene. The mixture requires to be very violently churned for a
, varying with the temperature, from five or ten minutes to half
ır. If the mixture is quite hot the emulsion is very easily and
y formed. It is quite thin while warm, but thickens on cooling.
, the process is delayed, but after continued agitation the emul-
ms suddenly, as in butter making, and becomes at once an ivory-
glistening paste, or jelly.

orm a perfectly stable emulsion more violent agitation is re-
than can be effected by hand stirring, or by dashing in an ordi-
hurn. The particles of oil and milk are more readily driven
ion by passing the mixture through the spray-nozzle of a force-

aquapult pump (Fig. 43), which is also one of the most effective in-
nts for spraying trees, may
ıfactorily used for this pur-
The pump is inserted in a
tub containing the mix-
nd this is pumped back
e same receptacle through
ible hose and spray-nozzle
the emulsion is formed.
5 to 5 gallons of emulsion
churned at one time by
of the ordinary hand form
pump. For larger quan-
larger pump or some form
ggist's churn will be re-

Fig. 43.—The aquapult.

emulsion, if well made, is
ient, provided it is not ex-
to the air, which causes in
partial separation of the
The union of the ingredi-
s purely mechanical, and
sence of the kerosene does
event the fermentation of
lk, which will become sour and curdle without, however, separat-
m the oil.

fresh milk may be substituted an equivalent of condensed milk
ater, or of sour milk. If sour milk is used no subsequent curd-
the emulsion takes place, and it is therefore preferable to sweet

milk emulsions may be diluted in water to any extent, and if
quire to be thinned at first with a small quantity of water.
art of emulsion to nine or ten parts of water will be found to
n effective wash.

*Soap and Kerosene Emulsions.*—The difficulty of obtaining fresh milk in Florida, and the cost of condensed milk, have made a cheaper substitute desirable. This is found in a solution of soap, which forms with kerosene an equally good emulsion. The quantity of soap used in solution need not exceed one-quarter of a pound to one gallon of water, but stronger soap solutions are required to form a permanent emulsion. The percentage of kerosene may also be varied greatly. But emulsions containing over 80 per cent. of the oil have too light a specific gravity and are not readily held in suspension in water. On the other hand, in the process of emulsification, kerosene loses a portion of its value as an insecticide, and emulsions containing less than 30 per cent. of the oil, although they do not at all, or only very slowly, rise to the surface when diluted with considerable quantities of water, are nevertheless too much weakened for effective use against Scale-insects.

The following formula is considered the best for general use. It gives a wash of sufficient strength to kill the eggs of those species of Scale-insect which are commonly found in Florida, although in dealing with some of the Aspidiotus scales a somewhat stronger emulsion may be required.

FORMULA:

| | | |
|---|---|---|
| Kerosene | 2 gallons | =67 per cent. |
| Common soap or whale-oil soap | ½ pound | =33 per cent. |
| Water | 1 gallon | |

Heat the solution of soap and add it boiling hot to the kerosene. Churn the mixture by means of a force-pump and spray-nozzle for five or ten minutes. The emulsion, if perfect, forms a cream, which thickens on cooling, and should adhere without oiliness to the surface of glass. Dilute before using, 1 part of the emulsion with 9 parts of cold water. The above formula gives 3 gallons of emulsion and makes when diluted 30 gallons of wash.

*Necessary precautions in the use of Kerosene.*—A reckless use of any penetrating oil upon plants cannot fail to prove detrimental. Kerosene is, however, much less injurious than the lighter oils, naphtha, benzine, &c., with which, in a crude state, it is associated. The refined oil, such as is commonly used for illuminating purposes, is safer, and should always be used in preference to the lower grades, which contain a large admixture of other oils exceedingly deadly to vegetation.

*Effect of Kerosene upon the Orange.*—Although the action of kerosene proves more injurious to some plants than to others, a healthy orange tree is but slightly affected by it, and will even support without serious injury applications of the undiluted oil if judiciously made, *i. e.*, applied in fine spray and avoiding exposure of the plant to hot sunshine or to frost before the oil has evaporated. Unhealthy trees and trees suffering from the attacks of Scale-insects receive a shock more or less

severe, according as their vitality is more or less impaired. Young, tender shoots, budding leaves and blossoms, are not much affected by kerosene, and may even be dipped in the pure oil with impunity.

The heat of the sun increases to an injurious extent the action of kerosene, and applications of very strong solutions or undiluted kerosene, if used at all, should be made on cloudy days or at evening.

Milk or soap emulsions containing 60 or 70 per cent. of oil and diluted with water ten times are more nearly harmless to the Orange than any other insecticide capable of killing the Scale-insect. Nevertheless the plant receives a shock, imperceptible when the tree is in good condition, but sufficiently severe when it is infested and injured by Scale to cause the loss of the old, devitalized leaves. Complete defoliation and the death of moribund twigs and branches may be expected to occur in extreme cases. The shock is invariably followed by a reaction, and in ten to fifteen days new growth appears. This growth is healthy and natural, and if the application has been sufficiently thorough to destroy the Scale-insect, results in permanent benefit.

Enough has been said to show that kerosene is a powerful remedy, perfectly effective and safe if used in moderation, but hurtful in strong doses; that its use undiluted is attended with danger, is entirely unnecessary, and cannot be recommended. In Appendix II will be found an examination of results obtained in experimental applications of kerosene, together with other insecticides, arranged in tabular form for convenience of comparison.

The most favorable season for applying kerosene washes is undoubtedly early spring or as soon as all danger of frost is past. The shedding of the last year's leaves, which takes place naturally after the orange tree has renewed its foliage in spring, is often accelerated by the action of the oil, which is thus made to appear very severe. But the loss of old and devitalized leaves is of slight consequence, and in the case of badly infested trees is a positive advantage, as the leaves in falling carry with them the scales most difficult to reach with insecticides.

*Whale-oil Soap.*—This has long been considered one of the best insecticides known, and is extensively used as a remedy for Bark-lice. Experiments show that very strong solutions kill the Coccids but have little or no effect upon their eggs. Solutions of one pound of the soap to three gallons of water failed to kill the adult Bark-lice or their eggs, and did not destroy all the young. The strongest solution used, one pound of the soap to one gallon of water, killed all the Coccids and few or none of the eggs.

This solution solidifies on cooling, and must, therefore, be applied hot. The effect upon the trees is about equal to that of effective kerosene emulsions; badly infested trees are somewhat defoliated, but new growth and vigorous trees are not appreciably affected. As the eggs are not killed, several applications at intervals of four to six weeks will be required to clear a tree of scale. (See Appendix II, table 2.)

Whale-oil soap is sold in Eastern Florida at 10 to 12 cents per pound. The cost of an effective wash is therefore much greater than emulsions of kerosene. For scrubbing and cleansing the trunks of orange trees this soap may be recommended. A solution of 1 pound to 4 gallons will probably be sufficiently strong for this purpose.

*Potash and Soda Lye.*—These substances have been recommended as remedies for Scale-insect in California. According to reports promulgated by the State Horticultural Commission, solutions as strong as 1½ pounds to the gallon of water are deemed necessary to exterminate the pest, and are said to have been used with good results upon Peach, Pear, and other deciduous fruit-trees. Although these caustic solutions burn and partially destroy the bark, it is said to be soon restored, and no loss of fruit results if applied in winter while the trees are dormant.

Experiments made in Florida upon the Orange with caustic soda and potash lyes show that solutions of 1 pound to 2, 2½, and 3 gallons were of little or no practical benefit as regards the extermination of Scale-insects, while the effect upon the trees was more severe than with applications of pure kerosene. Unlike kerosene, lye is injurious to the tender portions of the plant, and new growth is destroyed at once by strong solutions. Solutions of 1 pound to the gallon severely cauterize the leaves and tender bark, and kill back the smaller branches, but fail to destroy all the Bark-lice, and have hardly an appreciable effect upon their eggs. (See Appendix II, table 3.)

Concentrated potash is somewhat stronger than soda lye, but the results attained with it are also unsatisfactory. In the strongest applications, made with a solution of two pounds of potash to one gallon of water, the trees were burned as by fire, the leaves were charred without falling from the branches, all the growth under two years old was destroyed, and the main trunks alone remained alive. The Scale-insects perished with the cauterized bark and foliage; nevertheless, a very large percentage of their eggs escaped destruction, and continued to hatch. A few days later the young were seen in abundance, crawling over the blackened trunk and branches. It is probable that they all perished, however, through inability to penetrate the cicatrized bark with their sucking beaks. The trees thus treated survived, indeed, but in a mutilated condition and with an entire loss of symmetry in their tops.

It would appear from careful experiments and observations with both soda and potash lyes, that these substances are inferior to kerosene in killing power as regards Scale-insects, and far more injurious to the tree when used in solutions strong enough to be effective as insecticides. Weaker solutions are, however, extremely useful in cleansing the trunks of orange trees with the scrubbing brush. For this purpose they are superior to solutions of soap, and have an advantage over di-

great caution. Solutions, emulsions, and soaps containing it should
ry carefully mixed, in order that no globules of free oil may be
ed to come in contact with the bark of the tree.

action upon the Scale-insect is even more powerful than kerosene,
does not destroy as large a percentage of the eggs. The effect
the Coccids is not immediate, as in the case of other insecticides,
r three or four days after an application very few of the insects
At the end of a week, however, the Bark-lice are found to be
ed and continue to perish in increasing numbers for a week longer.
after the lapse of three weeks the destructive action of the oil is
ppreciable. These facts lead one to suspect that the insects are
in part at least, by the poisoning of the sap upon which they feed.
visible effect upon the plant appears to confirm this view. Leaves
nfested trees begin to drop after four or five days, and the defolia-
eaches a maximum during the second week. As is the case with
ne, the effect upon the tree depends upon its condition at the
f application; but carbolic acid is more severe in its action, and
is greater loss of leaves and infested branches. With care, how-
n application may be made sufficiently strong to exterminate the
ithout serious injury to the plant, and, as new or vigorous growth
y slightly affected, recovery is rapid.

following solution of crude carbolic acid will be found nearly if
uite as effective as a 64 per cent. kerosene emulsion, and may be
d without danger to orange trees. Dilute the carbolic acid with
its volume of soap solution (2 ounces common soap to 1 pint hot
). Mix thoroughly until all the oil is dissolved. Add, before
to one part of the above solution twenty parts water, and apply
ine spray as possible.

most effective method of using oil of creosote is to saponify it

SULPHURATED LIME.*—A combination of lime and sulphur, made by boiling the sublimate (flowers) of sulphur in milk of lime, is sometimes recommended as a "cure-all" for application to orange trees. The preparation contains a mixture of sulphides and sulphates of lime, together with varying quantities of the uncombined ingredients. By continued boiling the action of the sulphur is rendered more complete, and if an excess of lime is present the mixture becomes highly caustic, eating the skin from the hands and destroying the tender leaves and bark of plants. Its preparation is rendered unpleasant and even dangerous because of the sulphurous fumes that are given off.

One part sublimated sulphur, two parts lime, and ten parts water, boiled together half to three-quarters of an hour give the best results. After standing a short time the uncombined lime settles to the bottom, leaving a clear yellowish liquid, which, according to the United States Dispensatory, is "an impure aqueous solution of sulphide of calcium, necessarily containing hyposulphite of calcium."

Under varying conditions higher combinations are formed, and the chemical reactions are exceedingly complicated.[11] A large percentage of the yellowish-green mass consists of insoluble and inert sulphides, but with these are mingled other compounds of lime and sulphur, which give off sulphureted hydrogen gas (hydro-sulphuric acid), and are gradually altered by exposure to the air. When, therefore, the mixture is allowed to stand in open barrels, the sulphur compounds part with their active gases, and at length only the caustic action of the lime remains.

*Use in the Orange Grove.*—As an insecticide sulphurated lime has nearly the same value as potash or soda lye, and in like manner, by its caustic action, it kills the Bark-lice, but does not destroy their eggs, unless it is applied strong enough to injure the bark.

Its action upon the plant resembles very closely that of potash and other caustics, which are more injurious to the young growth than to the older and less vital parts of the tree.

The imperfect mixture formed by adding sulphur to lime in the act of slaking is deficient in strength, and has little value as an insecticide.

Sulphurated lime may prove useful to orange-growers as a destroyer of fungi, and it is advocated as a remedy for foot-rot or other diseases of a similar nature. But these claims, it is proper to state, have not as yet been substantiated by sufficient evidence.

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* The term "sulphurated lime" is here used as a convenience, and is made to include the various compounds formed by the action of hot water on lime and sulphur. In strictness, the monosulphide (Ca S.) is not formed by the wet process here given. It is thus described:

"Sulphurated Lime is a grayish-white, or yellowish-white, powder, gradually altered by exposure to air, exhaling a faint odor of hydrosulphuric acid, having an offensive, alkaline taste, and an alkaline reaction. Very slightly soluble in water and insoluble in alcohol. On dissolving Sulphurated Lime with the aid of acetic acid, hydrosulphuric acid is abundantly given off, and a white precipitate (Sulphate of Calcium) is thrown down." (United States Dispensatory, 1883, page 326.)

If used in sufficient strength to kill Scale-insects, the hands and arms must be protected from the liquid by rubber gloves, and care must also be had to avoid inhaling the poisonous gases exhaled.

In its active state the preparation is a depilatory, and by applying it as a paste the hair upon any part of the body may be reduced to gelatine and removed.

*Bisulphide of Carbon.*—The few trials made of this substance have not given very satisfactory results, and additional experiments are needed to determine whether it can be safely and economically used as a remedy for Scale-insects. Although a powerful insecticide, the extreme severity of its action upon the trees and the cost of the materials detract greatly from its value. It is an exceedingly volatile and explosive liquid, which must be kept in tightly-sealed glass bottles, and the fumes cannot be inhaled by man or other animals without danger. The bisulphide may be emulsified with oils and milk or soap, but not more than three or four fluidounces should be contained in each gallon of the diluted wash.

Appendix II, table 5, gives the result of some experiments with bisulphide of Carbon.

*Sulphuric Acid.*—A single experiment with sulphuric acid, 4 fluidounces in 6 quarts of water, applied with a brush as far as possible to all parts of a young tree, killed nearly all the Scale-insects, and very nearly killed the tree. The bark was blackened but not destroyed, and nearly all the leaves dropped. The tree, however, slowly recovered.

*Sulphate of Iron.*—This substance is exceedingly injurious to vegetation, but is, nevertheless, a very common ingredient of patent and proprietary remedies. Its presence can be detected by the inky-black or brown stains which it forms in the substance of the leaves and the rind of the fruit.

It does not affect the Scale-insect except by destroying the vegetable tissues from which it gets its subsistence.

*Ammonia.*—With this in a pure state no experiments have been made, but to its presence in fermenting urine is probably due the insecticide properties of the latter. Applications of urine have often been recommended as a remedy for scale, and are certainly not without value, but if allowed to stand and ferment, and especially if soot or other absorbents of the ammonia are mixed with it, it becomes highly injurious to vegetation, and if applied at all should be greatly diluted. A mixture of soot and fermented urine applied undiluted to a small orange tree effectually cleared it of scales, but very nearly killed the tree.

*Silicate of Soda.*—This is a thick viscid liquid, sometimes sold as a solid. It is readily soluble in water. When sprayed upon orange trees it soon dries and forms a coating of gum which partially peels off, carrying with it many of the old dead scales and some living ones. When applied in sufficient strength it kills most of the Coccids, but does not destroy the eggs. It injures the plant more than kerosene, with which it cannot be compared in efficiency or cheapness. The preparation is

inert and harmless to man, and acts mechanically by covering and stifling the Bark-lice or by removing them bodily from the tree. (See Appendix II, table 6.)

Very many substances used separately, or in various combinations, are recommended as remedies for Scale-insect. Among the number the following have been examined with more or less care and found to be of doubtful or of no value: sal-soda, muriate of potash, salt, lime, soot, and ashes.

Many otherwise valueless washes and applications have been rendered partially effective by the addition of a small quantity of free kerosene. The result in all such cases has been a very unequal distribution of the oil, some portions of the tree receiving a dangerous dose and other portions none at all. It seems hardly necessary to point out the uselessness of such half-way measures in combatting a pest which the most perfect remedy is powerless to eradicate unless applied with thoroughness and care.

## THE APPLICATION OF INSECTICIDES.

*Fineness and Force of Spray.*—In dealing with an enemy so thoroughly protected as are many of the Bark-lice, liquid insecticides should be applied in as fine a spray as possible, or at least in moderately fine spray, driven with considerable force, in order to increase to the utmost their penetrating power. The aim should also be to reach and thoroughly wet every portion of an infested tree, so that no individual Scale-insect shall escape the action of the liquid. This result is not attainable by the old method of sending a jet from a distance into the tops of the trees. An ordinary garden syringe is practically useless. There is needed a force-pump and a nozzle giving a finely atomized spray. This nozzle should be attached to a sufficient length of flexible hose to allow it to be introduced into the top of the tree. The orifice of the nozzle should be directed at a right angle to the hose, and not in line with it. The jet of spray may thus by a turn of the wrist be directed upward or downward, and brought into contact with all parts of the foliage and branches, from beneath as well as from the upper side.

*The Cyclone Nozzle.* (Fig. 44: 1, profile; 2, plan; 3, section).—A nozzle which answers the above conditions and is easily attached to any force-pump by means of a rubber tube is described in the report of the Entomologist (Report of the Commissioner of Agriculture for 1881–'82, p. 162). It consists of a shallow, circular, metal chamber soldered to a short piece of metal tubing as an inlet. The inlet passage penetrates the wall of the chamber tangentially, admitting the fluid eccentrically, and causing it to rotate rapidly in the chamber. The outlet consists of a very small hole drilled in the exact center of one face of the chamber. The orifice should not be larger than will admit the shaft of an ordinary pin. Through this outlet the fluid is driven perpendicularly to the plane of

rotation in the chamber. Its whirling motion disperses it broadly from the orifice, and produces a very fine spray, which may be converted into a cloud of mist by increasing the pressure in the pump. The perforated face of the nozzle-chamber is removable for convenience in clearing the orifice when it clogs. The diameter of the chamber inside need not exceed one-half inch and its depth one-quarter inch. A nozzle of these dimensions attached to the aquapult pump covers one and a half square yards of surface at a distance of 4 or 5 feet from the orifice. The amount of dispersion depends somewhat upon the thickness of the perforated face of the chamber. The diameter of the cone of spray may be increased by countersinking the exit hole and making its edges thin.

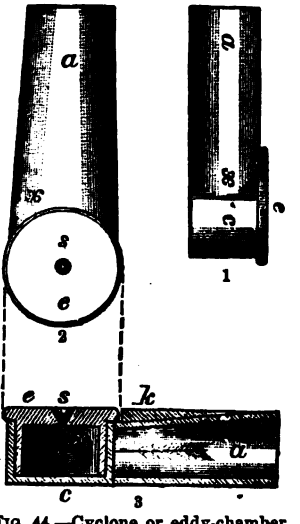

FIG. 44.—Cyclone or eddy-chamber nozzle. (After Barnard.)

Three-eighths-inch gum tubing is sufficiently large to supply one or a gang of several nozzles. The tubing must be strengthened with one ply of cloth.

In use, the end of the hose is supported by being fastened to a light rod of wood, which forms a handle, by means of which the nozzle may be applied to all parts of the tree. For full-sized trees a rod long enough to reach nearly to their tops must be used. For this purpose a convenient device may be made by passing the small rubber hose through a hollow bamboo rod of the required length. A three-sixteenth brass tube inserted in a bamboo rod has also been used.

Plate VII exhibits a complete outfit for treating orange groves with liquid insecticides, from a photograph taken during actual service in the field. This consists of a common pendulum pump inserted in a barrel and mounted upon a cart. The liquid is delivered through two lines of hose, each ending in a cyclone nozzle. The arrangement here shown permits the spraying of two rows of young trees at once, and thus effects a considerable saving in time. In the same plate is shown an aquapult pump fitted with a cyclone nozzle and a single length (12 feet) of three-eighths-inch hose. The pump is inserted in a pail, ready for use as a portable apparatus for one, or preferably for two men.

*Several Applications necessary.*—Unless exceptional care is exercised some portions of the bark or leaves will escape thorough wetting and isolated scales will be left alive. The eggs also to some extent will escape destruction and may hatch in sufficient numbers to restock the plant. As a rule, therefore, two, or even more, applications will be necessary. A second application should not follow too closely on the first. Sufficient time should be given for the hatching of all the eggs which may have been left alive. On the other hand, if delayed too long, a

brood interval will have elapsed and fresh eggs will be deposited. Successive applications should, therefore, be made at intervals of not less than three and not exceeding six weeks.

*Proper Seasons for applying Remedies.*—If kerosene emulsions are used trees may be treated for Scale at any time during the growing season. Strong solutions of lye, whale-oil soap, and other applications which are injurious to tender growth do least harm to the trees when dormant. The brood periods of Scale-insects are quite irregular, and breeding is more or less continuous throughout the year. As a rule, however, in Florida new broods begin in March, June, and September, and in these months, or the month succeeding each, the application of insecticides gives the greatest advantage. The period immediately preceding the appearance of each brood is that in which the majority of scales are filled with eggs, upon which many insecticides have little or no effect. The months of February, May, and August, and the winter months from November to January, are, therefore, seasons in which the application of remedies is likely to prove least effective.

To apply washes in winter is somewhat hazardous, and exposes the trees to risk of serious injury, by causing them to put forth new growth at a time when there is danger from frost. For in Florida the Orange is never quite dormant even in the coldest winter, and the reaction that follows an application is liable to start the buds unless the weather remains uniformly cool.

When the air is charged with moisture, and the nights are cold, with heavy dews or frost, the evaporation, even of volatile oils, is checked, and they remain too long in contact with the plant. Applications made under such atmospheric conditions sometimes prove very severe, and cause the tree to shed all its leaves, or even kill the branches.

# PART II.

## MISCELLANEOUS INSECTS AFFECTING THE ORANGE.

of fungus, but shows the oil-cells to be more or less completely emptied of their contents, and the outer layers, the epithelial cells, clogged with brownish resin, or entirely broken up and divided by fissures, which permit evaporation of the fluids from the underlying cells. The rind of rusted fruit, therefore, shrinks and toughens, and loses by evaporation or oxidation the greater part of its essential oil.

### THE ORIGIN OF RUST.

*Reasons for considering it the Work of a Mite.*—If we examine critically with a hand lens of considerable magnifying power the surface of a rusted orange, we will find here and there in the depressions, groups of minute white filaments adhering closely to the rind. Carefully transferring one of these filaments to the stage of a compound microscope, and applying a power of several hundred diameters, the character of the object is clearly shown. It is the cast skin of an insect.

If the examination chance to be made in winter, when the fruit is ripe, the number of these exuviæ will not be strikingly great. But if made in autumn or late summer, the surface of every orange showing rust will be found thickly sprinkled with them, and we shall be forced to conclude that we have before us the relics of a numerous colony, which at some former period infested the fruit.

Extending the examination to fruit that as yet shows no indication of rust, we will, if the season is not too far advanced, obtain abundant confirmation of this conclusion, and find these colonies in the full tide of their existence. The former occupants of the cast skins prove to be elongate Mites, of honey-yellow color, too minute to be seen as individuals with the unassisted eye, but visible in the aggregate as a fine golden dust upon the surface of the fruit.

*The Mite on the Leaves.*—Having tracked the Mite by means of its tell-tale exuviæ, and detected it at work upon the fruit, if we turn our attention to the leaves it needs no prolonged search to discover it here also, and in even greater abundance. In fact, it is evidently upon the leaves that the Mites exist and propagate throughout the year; for not only are they found upon fruiting trees, but upon plants of all ages, in the nursery as well as in the grove.

Nothing resembling the rust of the fruit follows their attacks upon the leaves. Each puncture of the Mites gives rise to a minute pimple or elevation, until the surface of the leaf becomes finely corrugated, loses its gloss, and assumes a corroded and dusty appearance.

This tarnished appearance of the foliage is very characteristic, and remains, a permanent indication of their depredations, after the Mites themselves have disappeared.

*First appearance of Mites on the Fruit.*—From the time when the cellular structure of the rind has completely developed, and the oil-cells have begun to fill, until the fruit is far advanced in the process of ripening; in other words, from early spring until late in autumn, it is

liable to attacks of the Mites, but it is in the intermediate period of its growth that the fruit offers conditions most favorable to their increase.

*Attacks of the Mite always followed by Rust.*—The evidence that rust follows as a sequence upon the depredations of this Mite is circumstantial rather than direct, but it is also cumulative. Oranges marked and kept under observation, but allowed to remain upon the tree, have in all cases rusted after being overrun by the Mites. Those upon which no Mites made their appearance remained bright to maturity.

A very large number of observations show a close connection between the occurrence of Mites upon the foliage and rust on the fruit, so that it may be stated as a rule, when the foliage of a tree retains its gloss, the fruit also will be bright, and, conversely, when the condition of the leaves indicates the presence of Mites in great numbers, the fruit will be discolored.

This is found to be true, not only of the entire tree, but of restricted portions. Thus the upper, the lower branches, or one side of an orange tree may produce rusty fruit while that on the other parts of the tree remains bright. In such cases there will always be a marked difference in the condition of the foliage upon the two portions, and the leaves surrounding the affected fruit will indicate more or less clearly the work of the Mites.

Other and perhaps more conclusive reasons for considering the Mite responsible for rust will be better understood when the habits of the Mite itself have been considered.

*Interval between the Disappearance of the Mites and the Appearance of Rust.*—As has been already indicated, the Mites do not permanently infest either the surface of the leaf or the rind of the fruit, but wander off to fresh feeding-ground when, through their combined attacks, all the accessible oil-cells have been emptied of their contents, or the tissues have been too much hardened by advancing maturity to be easily penetrated by their beaks.

The effects of their punctures upon the cellular structure of the plant, however, continue after their departure, and upon the fruit, rust develops with a varying interval, depending possibly upon the relative humidity of the air. Usually the discoloration is very apparent after the lapse of a week, and the rind continues to harden indefinitely, or as long as it is exposed to the air.

### THE RUST-MITE.

(*Typhlodromus oleivorus* Ashm.)

*Description.*—The so-called Rust Insect (Fig. 45, *a b*) is a four-legged Mite, honey-yellow in color, and about three times as long as broad. The body is cylindrical, widest near the anterior extremity, and tapers behind, terminating in two small lobes, which assist the animal in crawling and enable it to cling firmly to the surface upon which it rests. The front is prolonged in a conical protuberance, which appears to be

composed of two closely-applied lobes. The upper surface at its wide[r] part is marked on each side with shallow depressions, which are faint[ly] prolonged on the sides and reach nearly to the terminal lobes. Th[e] abdomen consists of about thirty segments. The beak, a short, curve[d] tube, is usually retracted between the organs of the mouth. The latte[r] form a truncated cone, concealed fro[m] above by the projection of the fron[t], and difficult to resolve into its compo[-] nent parts. Under high powers it ca[n] be seen to consist of at least two thick lobes, which in the living Mite have a reciprocal forward and back movement.

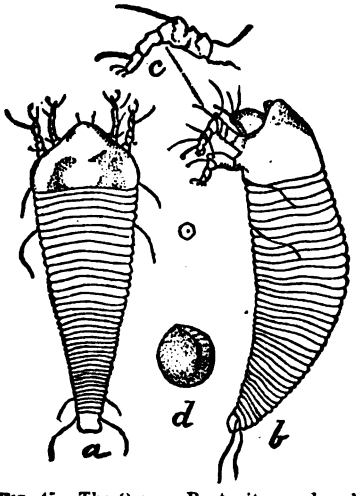


FIG. 45.—The Orange Rust-mite: *a*, dorsal view; *b*, lateral view—enlarged, the dot in circle indicating natural size; *c*, leg; *d*, egg, with embryo just about to hatch—more enlarged. (After Hubbard.)

The two pairs of legs are placed close together, at or very near the anterior extremity, and project forwards. They are four-jointed, and terminate in a curved spine, with opposing bristles. (Fig. 45, *c*.) The intermediate joints bear one or two very long, curved bristles. Several fine bristle-hairs, arising from the under surface of the body, curve upwards at the sides, and two very long bristles at the caudal extremity, curving downwards, are trailed after the Mite as it crawls.

The length of the adult Mite is $0.14^{mm}$ ($\frac{5}{1000}$ inch). The young do not differ essentially in structure from the adults, but are thick and short, almost cordiform, and the legs are very short.

The eggs, which are deposited singly or in little clusters upon the surface of the leaves, are spherical, transparent, with a yellow tinge. Their diameter is more than half that of the mother at its widest part, and they probably increase in size by the absorption of moisture after they are laid; otherwise the body of the Mite could not contain more than three or four fully-developed ova. The embryo is curved within the egg, its head slightly overlapping the tail. (Fig. 45, *d*.)

*Life-history.*—In hot weather the eggs hatch in four or five days, but in winter their development is more or less retarded by cold, although it is not entirely arrested even by frost, and the duration of the egg period seldom exceeds two weeks.

The young are bright, translucent yellow in color. Within a week or ten days they undergo a metamorphosis or molt, during which the animal remains dormant for about forty-eight hours. With its legs, which are placed close together, and stretched out in line with the body, and with its two-lobed anal proleg, it clings closely to the surface of the leaf. The form becomes more elongate and spindle-shaped. The body of the transforming Mite separates from the old skin, which be-

comes pellucid and empty at the extremities, and finally splits longitudinally, releasing the renovated Mite. The rejected pellicle is left firmly adhering to the surface on which it rests, but is in time removed by the action of the weather, and much sooner from the leaves than from the rind of fruit.

The adult Mite is slightly darker than the young in color, and becomes more opaque as it grows older. No sexual differences have been distinguished, nor has the act of coupling been observed.

Owing to the difficulty of confining the Mites without interfering with the conditions necessary to their existence, it has not been possible to determine the duration of their lives. It is, however, safe to conclude that they live several weeks after reaching the adult stage. The number of eggs deposited is also uncertain, but it is probably not abnormal, and the enormous populousness of their colonies must be attributed to rapid development, and comparative immunity from enemies and parasites, rather than to excessive fecundity.

*Food.*—This evidently consists of the essential oil which abounds in all succulent parts of the Orange and its congeners, and which the Mites obtain by penetrating with their sucking beaks the cells that lie immediately beneath the epidermis. That they do not feed upon the chlorophyl is shown by the color of their intestinal contents, which has no tinge of green, but a clear yellow, unmistakably indicating the source from which it came.

*Wandering Habits.*—While engaged in feeding, the mites remain quiescent for a length of time varying from a few minutes to half an hour. They then move on a short distance and again become motionless. If disturbed they have a habit of erecting themselves upon the leaf, clinging to its surface only by the anal proleg.

When dissatisfied with their surroundings, or when food becomes scarce, they wander restlessly about, and undoubtedly travel to considerable distances. Their rate of progress on a smooth surface is quite rapid, and amounts to 10 or 12 feet per hour. It is therefore not surprising to find them changing their position frequently; disappearing suddenly from one portion of a tree and appearing as suddenly in great numbers upon another and distant part of the same tree.

It is not to be understood that the Mites show any concert of action in moving their colonies, or that they are in any other sense gregarious than that they are usually found very thickly scattered over those parts of an infested plant which offer favorable conditions for their support. Thus the new growth of many orange trees becomes occupied or infested by them as rapidly as the leaves fully mature, and the number upon a single leaf may be estimated by many thousands.

*Numerical Abundance.*—The following examination, made in January, will give an idea of the extent of the brood during the coldest part of the Florida winter.

From a large number of leaves of late autumn growth one was se-

lected which showed an even distribution of Mites upon its surface. An area of one square inch was accurately marked out with a needle, and subdivided into sixteen equal squares. The number of Mites and their eggs upon four of the small squares, taken at random, was counted, and found to aggregate 1,142.* This gives for the square inch under observation 4,568 mites. The leaf was then cut into squares and triangles, and was found to cover 15 square inches upon a sheet of paper.

On the supposition that the experimental square inch gives a fair average, the number of Mites upon the upper surface of this leaf was 68,520. Certain portions, not exceeding one-quarter of the whole, were, however, more or less thinly populated. Deducting, therefore, 27 per cent. from the above, we have 50,020 Mites, the approximate population of the upper surface. The under side of the leaf was less thickly infested, but the number of Mites may be estimated as one-half that of the upper face, or 25,000. Thus the number of Mites and their eggs, upon a single leaf, is found to reach even in midwinter the enormous sum of 75,000.

In early summer, when the breeding is active, these estimates will be greatly exceeded. At times an orange tree may be so completely infested with the Mites, that of its thousands of leaves very few can be found free from their presence. If, then, we attempt to calculate the number that may exist contemporaneously upon a bearing tree, we find it represented not by millions but by billions, and the figures obtained convey no definite impressions to the mind.

*Preference shown for half Shade.*—An examination made on a bright, sunny day shows that, while the Mites cannot long endure the direct light and heat of the sun, they also avoid dark shade. At midday they are more abundant upon the under side of exposed leaves, and although they at all times show a marked preference for light, they desert those parts of leaf or fruit upon which it falls brightest. On a leaf partially exposed to the sun the Mites congregate near one edge in the morning, and in the afternoon cross to the opposite side of the same surface, following the shifting shade, which, by reason of its curvature, the edges of the leaf throw upon one side or the other.†

*Rings of Rust on Fruit.*—On the fruit, this preference of the Mites for half shade causes a phenomenon which will be recognized as very com-

* The number of eggs exceeded that of the Mites, a phenomenon not often observed, and which may be attributed to unusually cold and unfavorable weather at the time of the examination and for several weeks previous.

† The conditions most favorable to their increase are afforded by luxuriant foliage when thoroughly penetrated by light, but dense shade effectually bars their progress. Vigorous young trees on which the foliage is illuminated from beneath by radiation from the surrounding soil are especially subject to attack, the succulence of their leaves serving only to increase enormously the numbers of the invading host. The same luxuriance in older trees, whose branches interlock in the grove and shade the ground, acts unfavorably upon the productiveness of the Mites and checks their increase. These are facts of importance, as will be seen when we come to consider the means of combating the pest.

mon on rusty oranges. This is the occurrence of rust in a well-defined ring, obliquely encircling the orange as the ecliptic does the earth. The rust ring is seen most plainly on fruit from the upper portion and south side of a tree when it stands with others in a grove, and will be found to mark the band of half shade between the portion of the orange most directly exposed to the sun's rays and that in densest shadow. The surface covered by this penumbra band is precisely that upon which the mites gather most thickly in the middle of the day. Here their attack upon the rind will be most severe and its after effects most noticeable. (Plate VIII.)

There is also observable in rusted fruit a marked difference in the amount of discoloration upon the opposite sides. Even where no plainly marked ring is visible, the side of the fruit which upon the tree was turned towards the sun frequently presents a bright spot, and the opposite side an area of lighter bronze, with less sharply defined boundaries.

These facts, taken in connection with the observed habits of the Mites, may be regarded as the strongest evidence showing a connection between rust and their attacks upon the fruit.

*Influence of Weather.*—It has been already observed that the hatching of the eggs, although retarded, does not cease in cold weather, and that the breeding continues throughout the year. Frost, which is sometimes severe enough to kill the adult Mites, does no injury to the eggs, and the severity of a winter has little, if any, effect upon their prevalence during the following summer. In droughts, however, there is some evidence that many of the eggs dry up and are exterminated. The extremely dry seasons of 1881 and 1882 were followed in the winter of 1882–'83 by the brightest crop of fruit that had been known for several years.

*Agencies which assist in the Distribution of Mites.*—The activity of the Mites and their readiness to climb upon anything they meet in their path renders it evident that any living creature which passes from one tree to another is competent to transport the Mites with it. The tail-feathers of birds must sweep thousands from the surfaces of the leaves, and spread them from tree to tree or from grove to grove.

So readily do they relinquish their hold when brought into contact with a moving body, that the point of a needle swept across the surface of an infested leaf will usually be found to have several Mites adhering to it.

The same agencies which assist in the spread of Scale-insects undoubtedly serve to scatter the Mites. Not only do they climb readily along the webs of spiders, but they may frequently be seen upon the bodies of the spiders themselves, which do not seem to be at all disturbed by the restless movements of their little attendants.

The wandering habit of spiders is well known. Their method of bridging great distances by casting out hundreds of feet of silken line,

to be wafted by the winds and caught in distant trees, has often been noted. There is little doubt that of all other modes of dissemination, both of Scale-insect and Rust-mite, that of transportation by spiders is the most important, the most constant, and regular. The spiders bear with them upon their hairy bodies the young Bark-lice and the adult Mites, conveying them in their own migrations to distant points, and colonizing them under their protecting web whenever they chance to select the leaves of a citrus plant as their resting place.

And here is found the solution of that puzzling influence of the wind so often remarked in the case of Scale-insects, and which has led many to believe that they are disseminated directly by this agency, and therefore spread most rapidly in the direction of the prevailing currents.

Spiders of the web-making kinds are necessarily dependent upon the wind in making long voyages. The warm southeasterly winds of spring excite in them the migratory instinct, and at a time when the orange trees are swarming with the quickened life of Scale and Mite from a thousand projecting points of branch or leaf, the spiders are sending out their lines of rapid transit, and are bearing with them "on the wings of the wind" the seeds of mischief to the orange-grower.

### RAVAGES OF THE RUST-MITE.

*The Mite known only upon Plants of the Citrus Family.*—The Rust-mite attacks indiscriminately the various species of Citrus in common cultivation, but has not been observed to feed upon plants of any other genus. It is found upon the Lime, Lemon, Citron, Shaddock, Bigarde, and Tangerine, and none of the varieties of the Orange are known to be in any degree exempt.

Upon the leaves and fruit of all these species of Citrus the effects of its attack are essentially the same, although the rust is most noticeable on the Sweet and Bitter Orange.

*Effect of Attacks upon the Foliage.*—Like certain internal animal parasites which feed only upon the fat of their hosts, and do not touch its vital organs, the Mite does not destroy the vital functions of the leaf. The chlorophyl is untouched, and the plant is robbed of a portion only of its essential oil. The leaves never drop, no matter how severely attacked, but there is loss of vitality, and the growth of the plant is checked. This is especially noticed in young trees, which are frequently overrun by the pest in early summer, and during the remainder of the year make little progress.

The foliage of affected trees wears a dry, dusty appearance, and loses color. The leaves are without gloss, and become slightly warped, as in droughts.

*Rusted Fruit.*—If severely attacked by rust before it has completed its growth, the orange does not attain its full size. Very rusty fruit is always small. Its quality is, however, improved rather than deteriorated. The toughened rind preserves it from injury and decay, prevents

evaporation from within, and carries the ripening process to a higher point.

Rusty oranges can be shipped without loss to great distances. They keep longer, both on and off the tree, and when they reach the northern markets are superior to the bright fruit in flavor. Consumers not being aware of this fact, however, prefer the latter, and the reduced price of the bronzed fruit more than offsets to the producer its superior keeping and shipping qualities.

*Introduction and Spread of the Mite.*—Of the origin of the Rust-mite, whether native or introduced, we as yet know nothing. As far as has been observed, it is not found upon the wild orange trees in Florida, although it attacks them indiscriminately with others of the citrus family when transplanted to open ground, and it may exist upon them in small numbers in their native swamps.

It is said that a few years ago rust was entirely unknown; but the orange industry in this State is of such recent growth that attention has not long been directed to this matter. When but little fruit was produced, occasional discolorations of the rind would naturally pass unnoticed.

*Periods of Increase.*—As is the case with most invasions of insects, the pest, although increasing rapidly for a time, is likely to reach a maximum in a few years and afterward decline. This has been the experience in former years with Scale-insect, and is attributable to comparative immunity from enemies and parasites at the outset. As the number of their enemies increases, that of the destroyers diminishes, until in time a state of equilibrium is reached, which is disturbed only temporarily by the changing conditions of climate, or other and obscure causes.

It seems probable that the Rust-mite has reached or is already past the period of maximum destructiveness, and that succeeding years will witness its subsidence. The Mite has at present few enemies, and of these the most important are unfortunately not abundant. They give promise, however, of greater efficiency in future, as they belong to families many of whose members are as prolific as the Rust-mite itself.

*Geographical Distribution.*—Rust appears to be known upon the Orange only in Florida. Within the limits of the State, however, its presence is universal. No section, whatever claims may be made to the contrary, is exempt.

## REMEDIES.

*Influence of Soil and Methods of Cultivation.*—The effect upon the prevalence of rust of various systems of cultivation and of applications to the soil, for the purpose of changing its nature or supplying assumed deficiencies in its composition, has been the subject of endless discussion, and of experiments affording negative or conflicting results, which cannot profitably be reviewed here.

Suffice it to say, no method of combating rust by the indirect action through the plant of chemical substances applied to the soil has been proven effective. By forcing with fertilizers or high cultivation, no improvement is effected in the color of the fruit. This depends, not upon the condition of the tree, but rather upon the number of the Mites, which is, in fact, increased by an abundant supply of new growth and a constant succession of fresh and vigorous leaves.

It seems, however, to be an established fact that the fruit is less liable to rust upon low than upon high lands. Groves planted upon moist, rich hammock or clay soils produce, as a rule, brighter fruit than those upon high, sandy pine lands.

This result is commonly attributed to the abundance of moisture in low ground; but it may be more directly due to the denser shade afforded by a more vigorous foliage and reduced radiation from a darker soil. In the native wild groves, which are always densely shaded by forest, neither rust nor Mites are found, and the same immunity is enjoyed by cultivated trees planted in similar situations.

*Preventive Measures.*—Any means which will enable us to produce on the light, sandy soil of the uplands those conditions of shade which appear natural and grateful to the Orange, and which we have seen are unfavorable to the increase of the Rust-mite, should, if the foregoing account is correct, give immunity from Rust. In point of fact, there is strong evidence to warrant the belief that with intelligent management almost any grove may in a few years be made to produce bright fruit, by reducing the radiation and darkening the soil, (1) with mulch, or, still better, with a liberal coating of muck, (2) by encouraging the branches to grow low and spreading, and especially avoiding the vicious practice of trimming young trees too high.

Other ways of shading the ground and promoting vigorous leafy growth will occur to every orange-grower.

Those who advocate forest culture for the Orange may justly claim for it the advantage of affording comparative immunity from rust; but a discussion of the merits and demerits of this and other systems of cultivation must be left to the horticulturist.

It may, however, be proper to suggest that where isolation is practicable much can be accomplished toward the exclusion of such pests as the Rust-mite and the Scale-insect by properly arranged natural screens. Narrow belts of original forest, with its undergrowth, may be left, at least on the southeast side of the grove or on high land; the tall pines may be supplemented by hedge-rows of the native Holly, the Jujube, or other evergreen shrubs, which thrive upon uplands in the South.

Such wind-breaks not only protect the bearing trees and fruit from the whipping action of southeasterly gales, but afford the best and only hindrance to the spread of Mites and Bark-lice, prohibiting their direct importation upon spiders and other insects, through whose aid they are disseminated.

leaf with spray and collected upon blotting paper, began to crawl away as soon as dry, and showed no injury the following day. Eggs and molting young remained upon the leaf and were not affected.

(2.) Solution: 1 pound to 50 gallons. Applied in foam. Free Mites in great part killed. Molting young and eggs not killed.

(3.) Solution: 1 pound to 32 gallons. Adult Mites all killed. Molting young in part killed. Eggs not killed.

(4.) Solution: 1 pound to 16 gallons. Adult Mites all killed and shriveled, in two or three hours. Molting Mites, about 80 per cent. killed. Eggs, a large percentage killed.

(5.) Solution: 1 pound to 5 gallons. Adult Mites all killed. Molting Mites apparently all dead in two days. Eggs evidently affected, not all killed, but many collapsed by the second day.

(6.) Solution: 1 pound to 1 gallon. (This solution is nearly solid when cold.) Mites all killed. On the second day all the eggs appeared collapsed and dead.

The whale-oil soap usually supplied by dealers is inferior to that used in the above experiments. As an effective remedy for Rust-mite a solution of 1 pound to 5 gallons of water may be recommended. It should be applied in early spring, before the new growth begins. Two or three applications will be required, which should be made at intervals of one week. The cost of the wash, at the ordinary retail price for the soap (10 cents per pound), is 2 cents per gallon.

Very weak solutions may be made effective if used at frequent short intervals, but the labor and expense of making the numerous applications required will be very great.

A solution of 1 pound to 5 gallons will not injure the trees, but may cause the blossoms to drop. No directions can be given as to the greatest strength of solution that can be used upon blooming trees without loss of fruit, as this depends largely upon the condition of the tree. Solutions of 1 pound to 10 gallons can probably be safely used, in most cases, and will be effective if several applications are made at intervals of a few days.

*Sulphur.*—The Mites, both adult and young, are very sensitive to sulphur, and are readily killed by it in any form in which it can be made to act upon them. The eggs, however, are not readily affected, and even survive an exposure to the fumes, which will kill the plant. Fumigation cannot be resorted to without extreme danger to the life and health of the tree. The finely powdered (sublimed) flowers of sulphur does not affect the plant. It adheres more readily than might be supposed to the smooth surfaces of the leaves, and, especially when they are roughened by the Mites, it is not entirely washed away by heavy rains. Although it does not kill the eggs, it effectually exterminates the free Mites, which are sure to come in contact with it in their wanderings, and if it can be made to remain upon the plant, the young as they hatch are also destroyed.

Flowers of sulphur must therefore be regarded as one of the cheapest and most effective remedies for Rust-mite, and it may be used to great advantage in connection with whale-oil soap or other insecticides. It may be suspended in water and applied in spray. With proper appliances the dry powder may be sifted or blown upon the foliage when wet with dew or rain. A little wheat flour added to the powder would increase its adhesiveness.

The pharmaceutical preparation known as milk of sulphur (precipitated), although a much more finely divided powder, proves milder in its effect upon the Mites, and its cost will prevent its extensive use.

EXPERIMENTS.

(1.) A small seedling Orange infested with Rust-mite was covered with a nail-keg and fumigated for ten minutes by burning one ounce of sulphur under the keg. All the Mites were destroyed, but the eggs remained alive ten days, and finally dried up with the leaves of the plant, which was entirely killed.

(2.) Flowers of sulphur dusted over infested leaves through a loosely woven cloth. Free Mites all dead in twenty-four hours. Molting young all dead in three or four days. Eggs not killed in nine days, but young Mites killed soon after hatching.

(3.) Experiment No. 2 repeated in the open air, and leaves allowed to remain on the tree. Heavy rains on the second day did not remove all the sulphur. Results the same as in No. 2. Mites all killed. Eggs not killed.

(4.) Milk of sulphur dusted upon the leaves through muslin. Effect less powerful than in Nos. 2 and 3, but Mites in the end all killed. Eggs not killed.

(5.) Milk of sulphur; two ounces, by measure, of the powder suspended in one gallon of water. Leaves dipped in the liquid, when dry were lightly coated with grains of sulphur. Adult Mites dead on the second day. Some molting Mites and numerous eggs alive on the second day.

(6.) Leaf with Mites confined in a tight box with another leaf on which sulphur had been dusted. No effect after twenty-four hours. On the third day, however, only one adult Mite appeared to be alive. In six days all the Mites were plainly killed. Eggs not killed.

This experiment was repeated with sulphur scattered in the bottom of the box, and precautions taken to prevent its contact with the Mites. Results precisely the same as before.

*Note.*—By confinement in very tight metal boxes, Mites may be kept alive between one and two weeks, or until the leaves dry up or mold. The destruction of the Mites in this experiment was therefore due entirely to the slow volatilization of the sulphur.

(7.) Sulphuretted hydrogen. Leaves dipped in water strongly impregnated with the gas. In twenty-four hours all adult Mites were dead or dying. In thirty-six hours all free Mites were dead. In the

same time 40 to 50 per cent. of the molting Mites died. On the third day many molting Mites remained alive. Eggs not killed.

The above solution of sulphuretted hydrogen (sulphur water) was prepared by passing through two gallons of water, the gas given off by three ounces of sulphuret of iron, treated with dilute sulphuric acid.*

The remarkable results obtained with sulphur in these experiments, and especially the effect of the gas in solution upon the adult Mites, suggests the use of water from the sulphur springs which abound in various parts of Florida. Although it cannot be supposed that these natural waters contain a sufficiently high percentage of the mineral to render them powerful insecticides, their value cannot be determined without trial. Persistent applications may suffice to ultimately exterminate the Rust-mite or cause its disappearance from the trees. In view of its possible importance as a remedy, those who have access to natural springs or who now use flowing wells of sulphur water for the purpose of irrigation, should thoroughly test it by making repeated applications at short intervals.

*Kerosene.*—Emulsions containing 66 per cent. of kerosene oil, and diluted with water ten times, as in applications for Scale-insects, do not kill the eggs of the Rust-mite. The same emulsions, diluted one to twenty, kill nearly all the mites, but do not kill the eggs. With dilutions of one to forty, many adults escape destruction. In all the experiments made with kerosene upon Scale-insects the trees were not cleared of Rust-mites. They usually reappeared in numbers, within five or six days, owing to the hatching of the eggs. As a remedy for Rust-mite, therefore, kerosene is not as effective as either whale-oil soap or sulphur.

In making applications for Scale-insect it is advisable to render the wash effective against Rust-mite also, and this can be in a measure accomplished by adding sulphur.

Experience has shown whale-oil soap to be superior to condensed milk in forming emulsions, and much cheaper. Emulsions made with soap do not thicken or ferment, as when milk is used.

The formula given in the preceding chapter (see ante, page 94) gives the best results.

The emulsion should be diluted with water ten times, or in the proportions 1 to 9, and applied in fine spray.

In cases where an application is needed for both Scale-insect and Rust-mite the above wash, with two or three ounces of sulphur added to each gallon of the mixture, forms the most effective combination that can at present be devised. It is best applied in early spring, but should never be used in midwinter or when there is danger from frost.

*Carbolic Acid.*—Several experiments with crude Carbolic acid, saponified with lard oil and lye, or dissolved in strongly alkaline solutions,

*A solution of sulphuretted hydrogen may be very simply prepared by boiling sulphur in lime-water. (See Sulphurated Lime, *ante*, p. 98.)

powder disables and finally kills the Mites, but they are not as violently affected as many of the higher insects, and recover from slight applications.

*Lime.*—Not the slightest effect was obtained with applications of lime, as the following experiments will show:

(1.) Freshly air-slaked stone-lime dusted thickly over infested leaves. Mites continued feeding and propagating under the coating of lime-powder, and did not abandon the leaves during eight days in which they were kept under observation.

(2.) Slaked lime, 1 pint measure suspended in 1 quart water, and allowed to partly settle. Leaves dipped in the turbid liquid. No injurious effect upon the Mites or their eggs. Adult Mites were rendered restless by fine particles of lime adhering to them, and all left the leaves within two days, but were not killed.

(3.) Same solution as No. 2, clarified by standing several days. Leaves dipped in the clear lime-water. No effect whatever during eight days' observation.

*Ashes.*—Finely-sifted hard-wood ashes dusted upon the leaves produced no effect whatever upon the Mites, and did not seem to discommode them in the least.

The above experiments were made in December, during continued cold weather, which retarded the development of the Mites and interfered somewhat with observations as to hatching of the eggs under treatment.

## CAUTION.

There is danger in applying penetrating liquids to orange trees during the winter. First, because any shock to a dormant tree is apt to start the buds and induce new growth at a time when there is danger of frost. Secondly, a succession of cold nights and cloudy days, such as frequently occurs in severe winters, following immediately after an application, will increase to an injurious extent its effect upon the plant, by preventing evaporation of the liquids used, and allowing them to remain too long in contact with the leaves and bark. Serious loss is liable to follow a disregard of this warning.

# CHAPTER IX.

## INSECTS AFFECTING THE ROOT, CROWN, TRUNK, AND BRANCHES.

### INSECTS AFFECTING THE ROOT AND CROWN.

#### *TAP-ROOT BORERS.*

A grub or "Sawyer" is sometimes found boring into the tap-root of the Orange. No specimens have been examined, but from the descriptions given by competent observers, it can only be the larva of some longicorn beetle of moderately large size.

Mr. William H. Ashmead, in the Florida Agriculturist, February 16, 1881, mentions and gives a figure of a larva, which is possibly that of *Chion cinctus* (Drury), found boring in the tap-root of a Bitter-sweet orange tree. It was only discovered upon taking up the tree in order to transplant it, and may therefore be presumed to have done little damage.

A larva which appears to belong to this species has also been sent in Orange roots to the Department of Agriculture from Florida.

Other borers of this numerous and destructive family are likely to occur in the trunk and branches, as well as in the roots below the surface of the ground. It is difficult, without a previous knowledge of their habits, to suggest a remedy for these subterranean borers, but should they at any time become troublesome they may be removed by uncovering the roots and destroying the borer in its gallery with a pointed wire.

#### *WHITE ANTS OR "WOOD-LICE."*

*Habits.*—Termites or white ants are small, soft bodied insects resembling ants and living in numerous colonies. They shun the light and travel to great distances through galleries constructed beneath the surface of the ground. They feed for the most part upon dead wood and decaying vegetable matter, but sometimes attack living plants, especially those parts which lie below the surface of the ground. A certain amount of moisture is necessary to their existence, and very dry wood is usually free from their attacks.

### TERMES FLAVIPES Kollar.

[Fig. 46.]

This species is common from Maine to Texas, and is especially abundant in the South, where it invariably attacks wood buried in or lying upon the ground.

Each colony consists of numerous workers, among which are several distinct forms, and a few males and females. The females never leave the home nest, but, like the queen of the honey bee, devote themselves to producing eggs, which are hatched and cared for by the workers.

The central nests, in which are hived the queens and eggs, are rarely discovered, but generally exist in deeply-buried roots or in the hearts of stumps and logs of the largest size.

The workers extend their operations to immense distances, and, in search of food, excavate slender subterranean galleries, hundreds and even thousands of feet in length. It is, therefore, practically impossi-

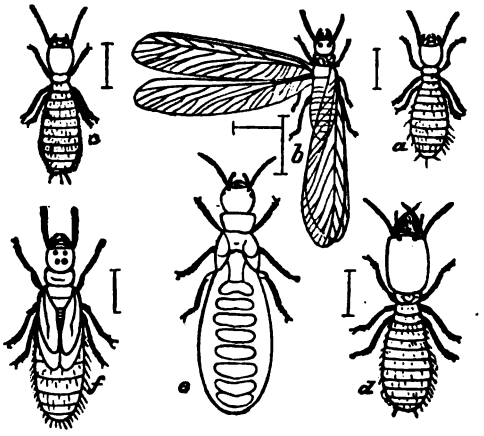

FIG. 46.—*Termes flavipes*: *a*, larva; *b*, winged male; *c*, worker; *d*, soldier; *e*, large female; *f*, nymph. (From the Am. Ent., Vol. II.)

ble to trace these galleries to their source, and by finding and destroying the brood nest to break up a colony.

Twice each year, in spring and fall, multitudes of winged males and females are produced, which swarm forth during the cooler parts of the day or after rains, and fill the air with their fluttering forms. Most of these fall a prey to birds, reptiles, insects, and other predatory animals, but many escape, and, after coupling, lose their wings, and in pairs seek suitable places in which to found new colonies.

*Injuries to Orange.*—Owing to their subterranean habits and avoidance of light, Termites are very insidious foes. Their vast numbers enable them to very quickly accomplish the work of destruction, so that often the finding a tree in dying condition is the first intimation which the orange-grower receives of their presence. Upon removing the earth

*On mulching and the use of decaying Wood as a Fertilizer in the Orange Grove.*—A mulch of muck, leaves, grass, pine-straw, succulent vegetable matter, and even well-rotted and disintegrated wood from old brush piles, does not in itself attract Termites, and its use is not attended with any danger, provided it is not piled against the trunk of the tree, the crown of which should in all cases be left exposed to the air. It is well to maintain an open space immediately about the tree, and the mulching should not be allowed to approach nearer than six or eight inches to the trunk on any side.

The practice of bringing brush, logs, and chips of wood into the orange grove, and either burying or allowing them to rot upon the ground, is hazardous, and will surely attract and colonize Termites, which, under any circumstances, must be considered dangerous and undesirable neighbors for orange trees. If disintegrated wood is used at all as a fertilizer, all solid fragments should be carefully excluded.

*Deep planting.*—This is a most frequent cause of trouble, and should be obviated by raising the trees too deeply set. In cultivating, also, the tendency of the earth to heap about the trees should be corrected by turning the furrows toward the centers between the rows, or by drawing back the earth with the hoe.

REMEDIES.—*Exposure to Light and Air.*—As Termites require for their existence darkness and moisture, on discovering their attacks the first step should be to remove the earth about the affected parts, and uncover the crown and root to a depth of several inches, at the same time removing with the knife, as far as possible, all the dead wood and bark, and exposing their galleries to the drying action of the air. In cases of slight attack this will generally suffice to drive them away.

*Hot Water.*—If the galleries extend too deeply into the wood to be readily uncovered with the knife, or if a numerous colony is found to have established itself at a considerable depth beneath the surface, a liberal application of hot water will usually reach and destroy them without injury to the tree.

*Pyrethrum.*—Termites are exceedingly sensitive to the action of this insecticide, and are invariably killed by contact with the powder. It may be used to great advantage whenever it can be brought into contact with the insects. Pyrethrum loses its properties rapidly on exposure to the air, and although it retains its power for a longer time when covered with earth, it remains effective for a few days only, and cannot be relied upon to permanently protect the plant from the attack of this or other insects.

*Penetrating Liquids.*—Kerosene in emulsion is very effective, and may be safely used in moderate quantities; but all penetrating oils should be applied with great caution to the roots of plants.

Bisulphide of carbon is most useful for destroying colonies remote from the trees, but is far too dangerous a substance to use upon or near the roots. The central nest, when its position is known, may be broken

up and the queens destroyed by pouring a few ounces of the liquid into the galleries, or into a hole made by a stake driven as close to the nest as possible. The hole should then be closed with earth to insure percolation of the vapor through the soil.

*Ashes, Lime, and Sulphur* are without effect in protecting orange trees from the attacks of Termites. In the cases where these substances have seemed effective in driving them away the result has been accomplished simply by the disturbance to their mines and exposure to the drying action of the air.

*Ingrafting Scions.*—Trees completely girded by Termites may be saved, if taken in time, by inarching scions between the root below and the stock above, thus reestablishing the connection between the two. The tree will in time restore the eroded bark, and the scions may be allowed to remain or may be afterwards cut out.

Supplementary stocks may also be planted close to the injured tree, and grafted in above the girdled portion, to sustain the life of the trunk and enable it to restore the severed connection. A poultice of mud and cow dung, applied to the injured part, will protect it and materially assist the formation of new wood and bark.

### CALOTERMES CASTANEUS.

A second species of Termite, somewhat larger than *Termes flavipes*, but otherwise closely resembling it, has been found in decaying branches and stumps of orange; but as far as its habits have been observed it is a tree-inhabiting species, seldom forming very large colonies, and not likely to do injury to growing plants, as it prefers very dry wood, and is most frequently found in dead branches from the tops of forest trees. Should it prove injurious to the orange it will probably require the same treatment as the related species.

## INSECTS AFFECTING THE TRUNK AND BRANCHES.

### *COLEOPTEROUS BORERS. "SAWYERS."*

### THE COMMON ORANGE SAWYER.

(*Elaphidion inerme* Newman.)

[Fig. 47.]

The larvæ of this beetle are cylindrical, whitish, fleshy grubs or sawyers, with rudimentary legs, which cannot be of much assistance to the animal in moving about, and a pair of strong short jaws. As with most borers of this family, the head is small and can be withdrawn entirely into the body. The first body-joint is somewhat enlarged, and

covered above with minute horny asperities, which are pressed against the walls of the burrow, and serve to hold the body firmly in place while the jaws are forced into the wood. The full-grown larva is about one inch in length.

The pupa is formed in the gallery, in a rude cell made by pushing aside the chips with which the larva stops up all the approaches to its burrow.

The perfect insect has a long, cylindrical body with rather roughly pitted surface; the color is dark brown, dusted densely beneath, but

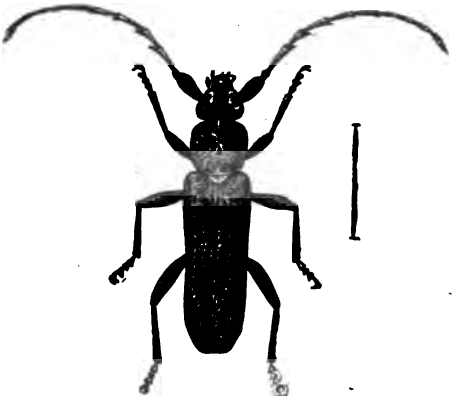

FIG. 47.—*Elaphidion inerme.* (Original.)

irregularly above, with fine ash-gray hairs; the antennæ are not longer than the body. The length varies from 11mm to 15mm ($\frac{44}{100}$ to $\frac{60}{100}$ inch); the males are smaller than the females.

Fig. 48 illustrates, in all its stages, *Elaphidion parallelum* Newm., a closely allied species, which lives in northern fruit-trees, and has habits similar to the Orange Sawyer. In the figure, *a* represents the larva; *b*, the pupa in its cell; *c*, the perfect insect; *d*, the head; *e*, *f*, and *g*, the mouth parts; and *h*, the antenna of the larva, enlarged; *i* and *j* show details of the antennæ and tip of the wing-cases, respectively, in the imago; *k*, the end of the twig which contains the borer.

FIG. 48.—*Elaphidion parallelum* Newm.: *a*, larva; *b*, chrysalis in twig; *c*, adult beetle; *d*, *e*, *f*, *g*, *h*, head and mouth parts of the larva; *i*, part of antenna; and *j*, end of wing case of the adult; *k*, end of twig, cut off. (After Riley.)

The larvæ of this beetle are more properly scavengers or pruners, feeding by preference upon dead branches, not only of Orange, but also of Hickory and other hard-wood trees, and confining themselves to the dry and lifeless wood, unless compelled by hunger to enter the living portions of the plant.

The injuries caused by them result from careless pruning, and, especially in the case of budded nursery trees, from leaving untrimmed the dead end of the stock above the insertion of the bud. These dead stubs attract the mother beetle, and she deposits one or two eggs in each.

The grubs that hatch confine themselves to the dead ends until they are completely hollowed out and reduced to mere shells, filled with sawdust. But if the supply of dead wood fails, they are forced to descend into the living stock below, and thus weaken the bud if they do not kill it outright, undermining the tissues which support it.

*Protection afforded the Tree by its Gum.*—Very frequently the larva in penetrating the living tissues causes its own death by suffocation from the flow of gum, which rises in the gallery, filling it to the top. This is particularly apt to occur in the case of Lemon, Citron, and others of the citrus family, which produce an abundance of gum. When in vigorous condition the trunk of the Orange is perfectly protected by its gum from the attacks of boring Coleoptera, and it is only endangered when, from loss of vitality, such as follows transplanting or disturbance from disease, attacks of Scale-insects, &c., the circulation of sap and the flow of gum are decreased.

*Necessary Precautions.*—It follows from what has been said that dead limbs, especially the dead ends of budded stocks, should be carefully trimmed off, back to and even with the healthy wood. Trees transplanted during an unfavorable season, and which do not get a good or early start, are apt to die back and present dead ends, which attract borers. Such trees need to be closely watched and kept pruned until their vigor is restored.

When trees of large size are cut off and budded, the entrance of borers in the ends of the stump or large branches should be prevented by protecting them with a coating of shellac or grafting-wax. It is also well to allow a few suckers to grow for a time on the side opposite the bud, in order to preserve a healthy flow of sap on this side and encourage the more rapid formation of wood and bark over the exposed heart wood.

It is in consequence of the sluggish flow of sap and drier condition of the wood on the side opposite the growing shoot or bud that this side of a budded trunk is particularly exposed to the attacks of borers; and most of their damage is done by undermining and killing the bark, with long galleries running down one side of the tree.

*Means of destroying the Borers.*—Should the borer be found to have penetrated the wood beyond the reach of the knife, no simpler method of destroying it can be suggested than the old one of following it to the bottom of its retreat with a piece of annealed wire sharpened at the end. If the wire is also slightly hooked at the end, the sawyer may generally be pulled out and removed bodily.

### THE TWIG GIRDLER.

(*Oncideres cingulatus*, Say).

[Figs. 49 and 50.]

This beetle is injurious to fruit and timber trees in all parts of the southern and eastern United States. The female has the singular habit of cutting off twigs and branches not exceeding three-fourths of an inch in diameter in which she had previously deposited a number of eggs. Fig. 49 shows the insect in the act of cutting a twig. In the South the Persimmon suffers most severely, but Oak, Hickory, Cherry, in fact, all hard-wood timber and fruit-trees, are attacked, and even climbers and ligneous shrubs like the Rose are not exempt.

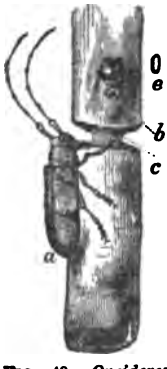


FIG. 49.—*Oncideres cingulatus*. (After Riley.)

No extensive depredations upon the Orange have hitherto been reported, but in most groves an occasional branch is amputated. The loss is seldom noticed except in young trees, which it is sometimes provoking to find deprived of their leaders of the previous season's growth. The cutting is so cleverly done as to pass for a malicious use of the pruning shears, and few persons would suspect it to be the work of an insect.

The beetle is about 16$^{mm}$ ($\frac{64}{100}$ inch) long, rather stout and cylindrical, dark chocolate-brown in color, speckled with lighter brown, and lightly covered with short, gray pubescence, resembling a coat of bluish dust or pruina, denser beneath and upon head and thorax, and forming a broad transverse band upon the wing-cases. The antennæ of the female about equal the body in length, and are somewhat longer in the male. There is but one brood each year. The eggs are laid in September and October, and are deposited singly beneath the bark, usually close to a bud. [Fig. 49, *b*; *e*, egg, natural size.] After placing an egg under each bud for a distance of two or three feet, the female cuts off the branch containing them by gnawing around it a deep, narrow groove, so nearly severing it from the tree that it falls by its own weight, or is broken off by the wind and falls to the ground, where it obtains the moisture necessary to the development of the young. The eggs hatch into white, fleshy larvæ of the form common to wood-boring beetles, and known in the South as "Sawyers." (Fig. 50, *a*.) The larvæ remain nearly a year feeding upon the wood of the fallen branch, which they riddle with their galleries, and in the latter part of summer form within the wood oval cells, in which they transform to pupæ. (Fig. 50, *b*.)

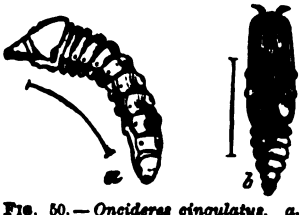


FIG. 50.—*Oncideres cingulatus*. *a*, larva; *b*, pupa. (After Riley.)

The perfect beetles appear again in September. They are very shy,

and remain perfectly motionless when disturbed. Their mixed coloration of neutral gray and brown is also admirably adapted for concealment upon all kinds of bark, and they are therefore not easily detected at their work.

*Remedies.*—The simplest means of destroying this pest is to gather up and burn during the winter the fallen branches which have been cut by them, and which contain their eggs or larvæ. Where persimmon bushes are abundant this will prove a work of some labor, but will be absolutely necessary if the Japan persimmon is cultivated for profit.

The Girdler is not likely to prove a very serious pest to the Orange, but should it ever become such some advantage may be gained by trapping the perfect beetles as soon as they begin to appear in the fall. This can be done by means of sirup daubed upon trees and fences. The sugared spots must be visited at night with a lantern, and the beetles, which will be found attracted to these spots, can be detected and destroyed. The sirup may be mixed with a little beer, wine, or alcohol to render it intoxicating, so that the beetles found feeding upon it will not be disturbed by the light of the lantern and try to escape.

## *INJURIES CAUSED BY ANTS.*

### SOLENOPSIS XYLONI McCook.

[Fig. 51.]

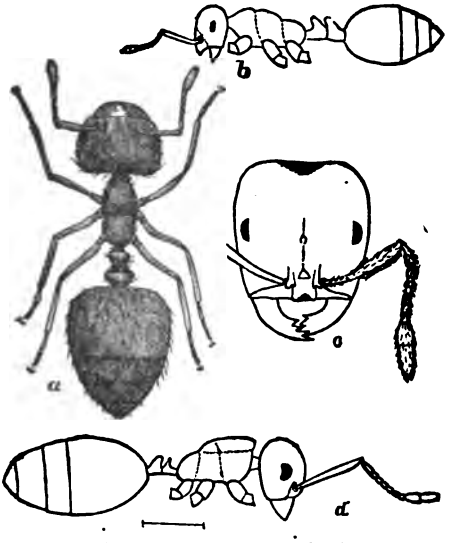


FIG. 51.—*Solenopsis xyloni*: *a*, ant from above; *b*, same, side view; *c*, same, view of head; *d*, queen, side view. (After McCook.)

The well-known carnivorous habits of this ant—it is one of the commonest and most effective destroyers of the Cotton Worm—would lead us to reject any but the most positive and direct evidence that it fed upon living plants. There is, unfortunately, no room to doubt that it does frequently and seriously injure the Orange by gnawing away the

bark, and causing an exudation of gum which seems, at certain seasons of the year, to become one of its principal sources of food-supply.

In obtaining this the ant is led by its instinct to make incisions at the base of the largest and most vigorous leaders at a time when, having nearly or completely attained their full growth, the young shoots are in process of hardening and ripening their wood, and the flow of elaborated sap to these parts is greatest, giving in consequence the most copious exudation of gum from a wound.

The ants make their attacks in force, and either girdle and kill the shoots or cut so deeply into their bases that they bend over or break off by their own weight. Sometimes, but rarely, the ants attack the old bark of the trunk and larger branches and gnaw holes in it, eating away the cambium layer without waiting for gum to exude. When the flow is very copious the ants bring sand and mix with the gum. This enables them to tunnel into it, and while some individuals are continuing the excavation in the bark beneath, others are penetrating the gum thus hardened and removing it piecemeal to their nests.

*Habits of the Ant.—Solenopsis xyloni* is a mahogany-brown ant of medium size. It is very pugnacious and stings sharply. It lives in large colonies, making its nest in the earth, and after rains throwing up irregular heaps of finely-granular earth. These heaps swarm with ants, among which are seen occasional individuals (workers major) with enormously enlarged heads. It is exceedingly fond of the nectar of plants and the honey-dew secreted by insects, and is a constant attendant upon Plant-lice and Lecanium Scales on the Orange. During the greater part of the year it is attracted by them alone, and its visits to the trees are harmless, but in October and November, when these insects are scarce, the ant turns its attention to the gum of the tree itself. During these months the summer growth is hardening and the bark is full of elaborated sap, containing a large amount of saccharine matter. It is probably in this condition only that the ants find it palatable and accept it in lieu of their ordinary food.

*Destroying Colonies.*—When not too near the tree, bisulphide of carbon may be used in breaking up colonies of this ant in the same manner as recommended for those of Termites. Pyrethrum powder, to the action of which they are very susceptible, stirred into the soil about and within their nest kills great numbers of the ants and frequently causes the survivors to abandon the premises. Naphthaline, in the form of a crystalline powder, used in the same way is equally effective in breaking up colonies. After frosty nights in winter, when the sun shines warm on the following morning, the ants come out of the ground and gather in clusters under fallen leaves or other objects affording them protection from the wind with exposure to the warmth of the sun. At such times an excellent opportunity is afforded to destroy the entire colony by raking over the ground about the nests, at the same time spraying the disturbed ants with kerosene or dusting them with pyrethrum.

*u of preventing the Ants from ascending the Trees.*—When they have
o attack a tree it is with extreme difficulty that they can be per-
ly driven off. Pyrethrum dusted over those upon the tree, and
d over the ground about its base, kills all the ants with which
in contact, and affords temporary relief, but its effect is not
and it does not always prevent their return. Coating the raw
th shellac and protecting the trunk with a band of tar and other
ibstances cannot be permanently relied upon to keep them off.
hn Lubbock, in his work on Ants, Bees, and Wasps, speaks of
nests of ants "by fur, with the hair pointing downwards,"
ire not told what kind of fur was used. A broad band of fur
ind the trunk of the tree, and with the hair pointing downwards,
ial in preventing their ascent. The skin of the rabbit has been
h success, but probably that of any fur-bearing animal would

es not form a barrier absolutely impassable to ants, and they
quently clamber through a very narrow band, but they expe-
reat difficulty in making their way against the hairs, and almost
ly become confused and turn back, if the distance exceeds 1 or

more simple and almost as effective is a barrier of chalk. This
d by rubbing a lump of dry chalk over the bark to form a band
8 inches wide, and completely encircling the trunk. In at-
g to cross such a band the ants nearly always slip and fall to
nd. The fine interstices of the bark are filled with loose grains
, in which their claws find a very treacherous support. While
d dry the chalk band is well-nigh impassable to ants of the size
ght of the Solenopsis, but dews at night, or rains, and the moist-
he atmosphere in a short time change the character of the sur-
causing the grains of chalk to cohere with sufficient firmness to
the weight of the insect and they then cross it in safety. The
annot, therefore, be regarded as a permanent one and requires
renewal, but it may be resorted to temporarily when a piece of
t at hand.

oft, fine clay, fuller's-earth, or talc may be substituted for chalk,
l cases must be applied by rubbing on from a dry lump. Good
annot be obtained by using any of these substances in powder,
s a whitewash applied with a brush.

# CHAPTER X.

## INSECTS AFFECTING THE TWIGS AND LEAVES.

### INSECTS OF THE ORDER HYMENOPTERA.

#### LEAF-EATING ANT.

(*Monomorium carbonarium* Sm.)

A small black ant eats holes in the leaves of orange trees when they are very young and tender, but seldom does any damage beyond destroying a leaf or two, which in most cases the plant can very well spare. Should this ant, however, become destructive, it may be combatted in the same way as the Solenopsis mentioned in the preceding chapter. A band of fur around the trunk of the tree will prevent their ascending.

### INSECTS OF THE ORDER COLEOPTERA.

#### BRACHYS OVATA (Web.).

This small beetle, belonging to the family Buprestidæ, is frequently met with upon the leaves, in which it occasionally eats small holes. The beetle is 5$^{mm}$ ($\frac{2}{10}$ inch) long and nearly the same in width. The body is flattened, or very slightly convex, and shield-shaped. The color is a mixture, finely mottled, of dark and light bronze. When disturbed, the legs are drawn into grooves in the underside of the body and the beetle falls to the ground, where it bears a remarkably close resemblance to the seeds of some of the common wild vetches. The beetle has not hitherto been known to do appreciable damage to plants of the citrus family. Its natural food is the Oak, upon which its strangely-flattened larvæ live as leaf-miners, excavating galleries in the narrow space between the upper and lower surfaces of the leaves, and feeding upon the parenchyma.

### ODONTOTA RUBRA (Web.)

A beetle of the leaf-eating family Chrysomelidæ is occasionally found eating the leaves of Orange, but never to an injurious extent. Like the preceding, its larva is a leaf-miner, and is found on various plants, but not upon the Orange.

### NOTOLOMUS BASALIS Leconte.

[Fig. 52.]

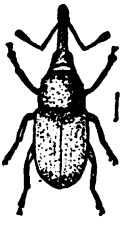

FIG. 52. — *Notolomus basalis.* (Original.)

A weevil or snout-beetle (family *Curculionidæ*) of small size and light straw color, frequently found upon the trees, usually hiding in dead leaves or tangles of spider-web. It has been seen to eat the leaves and tender bark, but it nibbles rather than feeds upon the Orange, and cannot be convicted of doing serious harm. When the Orange is in bloom the beetle is quite common upon the flowers, and it feeds upon the pollen and nectar without injury to the plant. The early stages are not known, but it is suspected of a connection with the Saw-palmetto, upon the bloom of which the beetle is always found in abundance.

### THE ORANGE LEAF-NOTCHER.

(*Artipus floridanus* Horn.)

[Fig. 53.]

This is a snout-beetle of bluish-white color, stout, cylindrical form, 6$^{mm}$ (¼ inch) in length. It is said to eat jagged notches in the edges of orange leaves (see Report of Commissioner of Agriculture for 1879, p. 207), and was also found by Ashmead on the Florida Keys feeding upon the Lime and other plants. (Orange Insects, p. 62.) The beetle is confined to the peninsula of Florida, and is rare except in the extreme southern portions of the State.

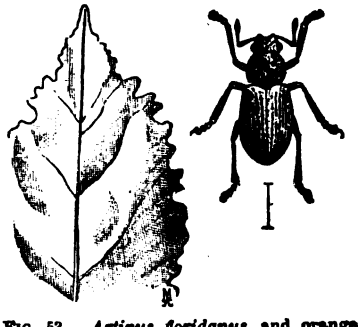

FIG. 53. — *Artipus floridanus*, and orange leaf with edges gnawed by the beetle. (After Comstock.)

### PACHNÆUS OPALUS, Olivier.

A weevil similar in form and color to the preceding, but one-half larger. Ashmead, in his Orange Insects, p. 61, says: "This weevil was caught by me in great quantities in South Florida on the Keys, feeding on the leaves of the lime-tree (*Citrus*). I also found it eating the leaves of *Baccharis halimifolia* and *Borrichia frutescens*, which I think are its natural food plants." It is certainly very rare on the mainland, and does not occur

in the northern part of the State. Both this and the preceding species may be removed, as suggested by Mr. Ashmead, by shaking them from the trees into cloths spread to receive them. They fold up their legs and simulate death, when disturbed. The early stages of both species remain unknown.

## INSECTS OF THE ORDER ORTHOPTERA.

### THE ANGULAR-WINGED KATYDID.

(*Microcentrum retinerve* Burm.)

(Plate IX.)

This large, green grasshopper, common in all parts of the United States, has been exhaustively studied by Professor Riley, and its full history detailed in his sixth Missouri report. It has been several times noticed in reports of the Department, and is quite fully treated in the report for 1880. The eggs—large oval objects, flattened like flax-seed and dark gray in color, are placed overlapping each other in a row along the edge of an orange leaf, or are deposited in two parallel rows along a twig. There are two broods each year. Eggs laid in December hatch in January or February. The young complete their growth in eight or nine weeks. The eggs of the second brood begin to appear in May, and are continually being deposited during the summer. Young of the second brood are first seen in July.

Throughout their lives, the Katydids feed upon the Orange. The young confine themselves to the tender foliage, but the adults often gnaw the bark of growing shoots and leaders, and thus inflict very serious injuries. Occasionally a tree is almost defoliated by Katydids, and this, of course, happens most frequently in the case of young trees; but, owing to the luxuriance of its foliage and the rapidity with which the orange-tree renews its lost leaves, the damage done by these insects is rarely sufficient to repay the cost of fighting them. Young groves should, however, be protected from their attacks, and early in the winter the trees should be examined and the leaves with eggs upon them removed. The young may very readily be killed by dusting the foliage with pyrethrum powder.

EGG-PARASITE OF THE KATYDID.—(*Eupelmus* [*Antigaster*] *mirabilis*, Walsh.)—(Plate IX, Fig. 2, female; Fig. 2*a*, male.)—The eggs of the Katydid are very frequently found with a small, round hole cut through the side. This is the exit-hole of the parasite which is hatched and bred within the egg of the Katydid, feeds upon its contents, and in due course issues forth, a four-winged fly. The larva, like that of most Hymenopterous parasites, is a transparent, white, footless grub; the pupa of the female is flattened, and is very curiously packed in its narrow quarters, so that it exactly fills the space within the egg-shell. To

accomplish this, the abdomen and legs are folded back over the body, and it is remarkable that the perfect insect retains through life the power of thus rolling itself up into a ball. In the imago stage the two sexes are very dissimilar. The female has clouded wings, the body shows metallic reflections of purple, green, and copper-bronze, and the abdomen is black, with the first joint white. The male is smaller than the female, has clear wings, and is uniformly bright metallic green in color. It has not the power of rolling itself like the female.

### THE LUBBER GRASSHOPPER.

(*Romalea microptera* Serv.)

(Fig. 54.)

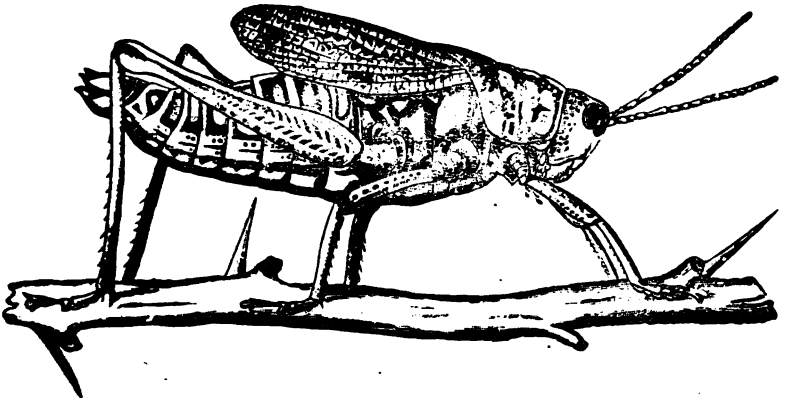

FIG. 54.—The Lubber Grasshopper. (After Glover.)

This huge locust has nomadic habits, and wanders about in search of food, attacking almost all succulent plants. It sometimes does damage to orange trees by feeding upon the leaders and tender shoots, and is at times sufficiently abundant to become a serious pest. The eggs are laid in the ground and hatch in March or April. The young are black, with bright yellow markings. For several weeks after leaving the ground they are gregarious, each brood in its wanderings keeping together and gathering at night in a cluster upon some low herbaceous plant. This habit, with their conspicuous coloration, renders it an easy matter to find and destroy them at first. Later in the summer they separate and become scattered, and the separate individuals must then be sought for and destroyed.

During its growth the insect several times changes its skin. After the final molt, which takes place in July or August, its appearance is entirely changed. The colors of the young are reversed in the adult; yellow becomes the predominant color, and the body is marked with spots and lines of black. The wings are tinged with pink; they are too short and rudimentary for flight. The adult insect is nearly 3

inches long, exclusive of its members; it is very heavy, clumsy, and slow in its movements.

There is but a single brood; after depositing its eggs, in September and October, the insect disappears and is not seen again until the young come out of the ground in the following spring.

*Absence of enemies.*—The Lubber Grasshopper has no known enemies. Predaceous animals cannot be induced to feed upon it, and doubtless its juices have an acrid and disagreeable flavor. Its sluggish habits, taken in connection with its conspicuous coloration, show that it has little need of concealment, and that it does not fear attacks of enemies. The eggs are probably preyed upon by some species of Bee-fly (*Bombyliidæ*), but if such an enemy exists it remains as yet undiscovered.

*Remedy.*—So large and conspicuous an insect is not likely ever to prove an alarming pest, and hardly requires elaborate directions for its management. If care is taken to destroy the young broods by trampling upon them when they appear in early summer, and before they have scattered, there will be an end to anxiety from this source for the season, and with a little pains taken at the proper time for two or three successive seasons a farm may be entirely rid of these 'hoppers, even if previously much infested by them.

### OTHER LOCUSTS (*Acridiidæ*).

The various species of Acridiidæ, grasshoppers, as they are commonly called, nibble the leaves of orange trees, but do serious injury only where weeds are allowed to grow up around the trees. From their size and voracity the species of the genus Acridium, of which three are found in Florida, are most injurious. They are large insects, 2 or 2½ inches long, and are very active, jumping and flying to great distances.

In *Acridium obscurum* Burm. the general color is olive green, with fuscous dots and a yellow stripe from the head to the tip of the closed wings. The wing-covers are chocolate brown.

*Acridium americanum* Scud. (Fig. 55) is very similar, but the general

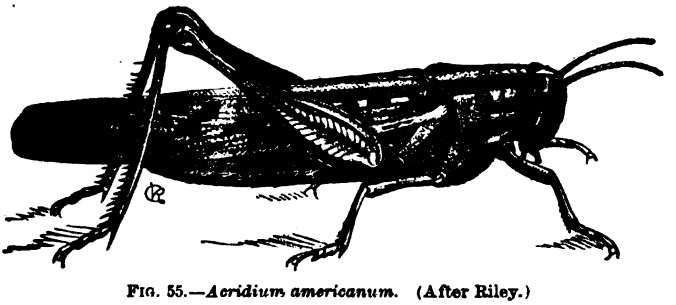

FIG. 55.—*Acridium americanum.* (After Riley.)

color is reddish-brown and the wing-covers are marked with large brownish spots.

*Acridium alutaceum* Harr. is dull brownish-yellow in color, and the

wing-covers are marked with small spots. Like the Katydid, these larger grasshoppers occasion loss of growth, and stunt the plant by eating back the succulent ends of the shoots, as well as by consuming the leaves. With clean culture, and keeping the grove free from weeds and succulent plants, very little trouble will be experienced from the ravages of locusts, which are only attracted in numbers by dense masses of vegetation.

## INSECTS OF THE ORDER LEPIDOPTERA.

### THE ORANGE DOG.

(*Papilio cresphontes* Cramer.)

[Plate X and Plate XI, Figs. 1 and 2.]

The most important enemy to the Orange among this group of insects is a caterpillar 2½ inches long, of a dark brown color, with large blotches and markings of cream color. (Plate X, Fig. *b*.) The anterior part of the body is enlarged, and when at rest and not feeding the head is drawn in and turned under. The swollen extremity then presents a hideous, mask-like face, or dolphin head, of which the upper portion of the true head forms the snout, and two velvet-black spots in deep depressions on each side do duty as eyes. When irritated, the larva shoots forth from a fold just back of the head two long, fleshy, orange-colored tentacles, resembling a pair of horns. (Plate X, Figs. *c* and *d*.) . These are scent-organs, emitting a penetrating odor, disagreeable alike to man and beast.

When full-grown, the larva retires to the vertical trunk or to some large branch of the tree, weaves a mat of strong thread to which it fastens itself by its terminal hooks, and with its head directed upwards slings itself at an angle to the trunk by means of a silken band passed around its body and fastened at the ends to the bark. Within this loop it changes to chrysalis by casting its larval skin. The chrysalis (Plate X, Fig. *e*) is a remarkable example of protective mimicry; the mixture of grey and b own colors, together with irregularities of form, such as projecting points upon the breast and at the upper end, give it a very close resemblance to a dead, lichen-covered twig.

From this somber-colored case issues in time a large and gaily-colored butterfly, with wings above velvet-black, crossed by a double series of large yellow spots, and beneath yellow with black veins (Plate X, Fig. *a*). The under wings end in tails, and are adorned above with a pair of eye-like spots of red edged with black and surmounted by a thin crescent of blue. Upon the under side these spots are repeated, with the addition of a second pair of red blotches and a complete row of pale blue crescent-shaped spots.

This showy butterfly is one of the commonest insects in the South, and is seen everywhere flitting about in the orange groves.

*Life-history.*—The eggs are spherical, smooth and pearly in luster, with a dull red or reddish-yellow tinge, and are deposited singly, invariably upon the youngest and most tender shoots, usually upon the tips of the budding leaves (Plate XI, Fig. 1). The butterflies appear with the opening of spring from chrysalids formed in November and December. The first eggs are deposited early in February, or as soon as the new growth appears upon the orange trees. The eggs hatch in ten or twelve days. The caterpillar completes its growth in about thirty days, and remains in pupa from ten to fifteen days. About two months is thus occupied by a single brood, and there are four full broods during the season beginning with February and ending with October. The breeding is, however, continuous during the summer, and eggs are laid whenever new growth appears upon the orange trees.

The ovaries contain over five hundred eggs, the laying of which occupies the female many days; she scatters them over a wide area, seldom depositing more than four or five upon a single plant. The young caterpillars feed at first only upon the tenderest leaves, but when well grown demolish both leaves and shoots which have not hardened into wood.

On account of its large size and voracity, the Orange Dog does great damage, particularly to young trees, which are sometimes completely defoliated. It has other food plants besides the Orange; among the number the species of Prickly Ash (*Zanthoxylum*) are mentioned by several authors. It is found commonly in the swamps of Florida, feeding upon the Tupelo (*Nyssa aquatica*, L.) and upon the Red Bay (*Persea carolinensis*, Nees). It seems, however, to prefer the Orange and its relatives to all other plants.

*Defensive measures.*—Hand-picking is not a very difficult task in the case of so large an insect, and must in most cases be relied upon to keep young trees free from Orange Dogs. As the eggs are quite large, and conspicuously placed at the tips of the growing stalks and budding leaves, it is a simple matter to find and pinch them between the fingers. A very little practice will enable the orange-grower to go rapidly through his young grove and destroy by hand nearly every egg. If this method is systematically pursued, the result will well repay the trouble. Two rules should be borne in mind, and will greatly facilitate the work. (1.) Only those trees which are pushing out tender sprouts need be examined for eggs and young larvæ.* (2.) In nearly all cases the eggs are laid upon sprouts at the top of the young tree and not upon those low down and near the ground.

* While this rule in regard to the disposition of the egg can be predicated with great confidence for the orange district of Florida, it is but just to observe that it may not hold good for Louisiana and other more northern localities. Mr. L. O. Howard has in fact found the eggs of *Papilio cresphontes* upon the older leaves, and on the twigs of orange trees, growing in public parks in the city of Savannah, Ga. The observation was made about the middle of August.

A great deal can be accomplished towards reducing the numbers of the Orange Dog, by destroying the butterflies; the most effective implement for this purpose is a light fowling-piece, loaded with dust shot or coarse salt. It may seem somewhat ridiculous to advocate the shooting of butterflies, but an insect which has a spread of wing of four or five inches affords a by no means despicable object for target practice. A more certain method for those not skilled at shooting on the wing is to attract the butterflies from a distance by planting in some convenient place a bed of flowering plants. It is a common sight to see a dozen or more individuals of this butterfly hovering over a garden bed of Phlox or Zænias, within easy range of the drowsy orange-grower, as he takes his midday siesta upon the veranda. What a loss of opportunity it is to allow these foes to escape and continue their havoc in the orange grove.

PARASITES.—*A Tachina fly*, with a hairy body, and somewhat larger than a common house-fly, which it superficially resembles, attacks the caterpillars when partly grown, and deposits upon each several elongate, oval, white eggs; these hatch maggots, which penetrate the skin of their host and feed upon its body-contents, eventually killing the worm. The tachinized caterpillar usually attempts to pupate, but strength fails, and it dies suspended in its silken loop. The parasitic maggots eat their way out and drop to the ground, in which they form oval puparia. They emerge as flies in twelve or fifteen days, or, if the season is far advanced, remain in the ground during the two or three months of winter, and issue with the return of warm weather in February. From four to eight flies are bred from a single Orange Dog.

*Chalcis robusta* Cresson. (Fig. 56.)—From the chrysalis of *Papilio cresphontes* there sometimes issues, instead of the butterfly, a four-

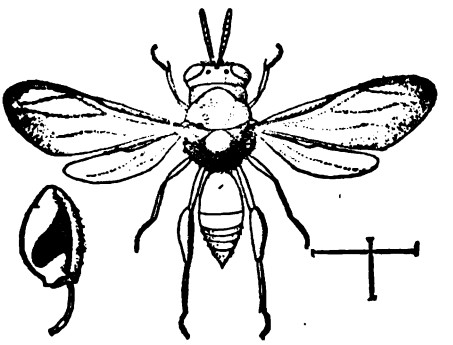

FIG. 56.—*Chalcis robusta*. (Original.)

winged fly. This parasite is a large and handsome member of a family, the Chalcididæ, composed for the most part of minute forms. It is 8.4$^{mm}$ ($\frac{1}{10}$ inch) long; in color black, with golden-yellow legs. The posterior thighs are swollen, and adorned with an oblique band of black

across the middle. The wings are smoky. The head and thorax are very coarsely punctured, and clothed with short, golden hairs. The fly in quitting its host makes a large, round hole in he side of the chrysalis. All the specimens obtained emerged in June or July from pupæ of the second brood. There can be no doubt that this parasite would in case of undue multiplication of the Orange Dog become an efficient check upon its increase. At present, however, it is somewhat rare.

### *SLUG CATERPILLARS—STINGING CATERPILLARS.*

Several species of Bombycidæ, called "slug caterpillars," because of their apparent want of legs, and their gliding, snail-like movements, are occasionally found doing damage to orange trees by feeding upon the leaves. The hairy species are known as "stinging caterpillars," being provided with nettling hairs. They are all of rather large size, an inch or more in length, and have sluggish habits. They construct stout and very tough cocoons, attached to the bark of the tree, and they know how to conceal them with great art. The perfect insects are moths, with rather thick, heavy bodies, covered with long, downy hairs, and flying only at night. The four species which are known to feed upon the Orange are *Lagoa opercularis* Sm. & Abb., *Empretia stimulea* Clem., *Phobetron pithecium* Sm. & Abb., and *Limacodes scapha* Harr.

### LAGOA OPERCULARIS Sm. & Abb.

[Figs. 57, 58, 59.]

The caterpillars of this moth are covered with long, silky hair, underneath which are concealed shorter, stiff hairs, exceedingly sharp at the points, and powerfully nettling when they penetrate the flesh. Upon some persons the invisible wounds made by these hairs produce swellings, and an amount of irritation equivalent to a sting; the larvæ are, in consequence, popularly supposed to be very poisonous. When young the caterpillars are white and resemble a flock of cotton wool. They undergo six molts, at one of the last of which they become darker, the color varying in individuals, from red-brown to light clay-color. When full-grown the larva presents the singular appearance of a lock of hair possessing sluggish life and a gliding, snail-like motion. It is 1½ inches long, bluntly rounded in front and diminishing rapidly to a point behind. The hair rises in a sharp ridge upon the back, and forms several tufts of rust-red color.

Fig. 57.—*Lagoa opercularis*, larva. (After Riley.)

The cocoon (Fig. 58) is placed in a crotch of the tree or upon a branch of considerable size; it is 20$^{mm}$ ($\frac{8}{10}$ inch) long, oval, convex, flattened on the side next the tree, and fastened very firmly to the bark. The upper end is abruptly truncate, and fitted with a hinged trap-door,

which is readily pushed open from within by the escaping moth, but does not yield to pressure from without, and is so accurately fitted that no tell-tale crack can be discerned. Upon the back of the cocoon is an elevation formed by the meeting of several folds and ridges, forming a marvelously exact imitation of a winter bud. The ends of a lock of hair from the body of the caterpillar counterfeit the down which in nature protects the dormant bud. The substance of which the cocoon is made is a tough parchment, composed of agglutinated silk, in which is felted the long, hairy covering of the larva. Its color is a neutral brown, closely approximating to that of the bark upon which it is placed. The entire arrangement is a most successful representation of the stump of a small branch broken off near its junction with the main stem, and upon which is plainly shown the swelling of a bud.

FIG. 58.—*Lagoa opercularis*, cocoon. (Original.)

FIG. 59.—*Lagoa opercularis*, moth. (Original.)

The perfect insect (Fig. 59) is a moth with a very wooly body, pale yellow, tinged with brown. The fore wings are umber-brown at the base, fading to pale yellow outwardly; the surface is marked with fine wavy lines of silver gray, and the fore margins are nearly black. The legs are yellow, with dusky feet. The wings of the male moth spread about one inch; those of the female an inch and a half.

*Life-history.*—The larva is a very general feeder, and although the Oak appears to be its principal food plant, it is occasionally injurious to the Orange. It never injures the bark or tender shoots, but subsists only upon the mature leaves.

There are two broods, one in early summer and the other in the fall. The larvæ of the second brood form their cocoons in November or December, and in them pass the winter, not changing to pupa until the following March or April, or about two weeks before the moths appear.

*Parasites.*—The same parasites have been bred from Lagoa as from the Orange Dog. Tachina flies issued in June from a cocoon found on Orange in March. The hymenopterous parasite *Chalcis robusta* issued September 15 from a cocoon collected August 27.

## THE SADDLE-BACK CATERPILLAR.

(*Empretia stimulea* Clemens.)

[Figs. 60 and 61, and Plate XI, Fig. 3.]

The caterpillar of this species, also a general feeder, is short and thick, and very strangely marked with a large, quadrate patch of green, in the center of which is an oval spot of purple, so that the animal

appears to have thrown across its back a green cloth surmounted by a purple saddle. The fringing hairs along the sides of the larva have irritating properties like the concealed nettling hairs of Lagoa.

The cocoons are short, oval, almost globular, flattened against the branch to which they are attached, and are of the same tough, parchment-like material and brown color as in Lagoa. They are usually placed in concealment, often against the main trunk of the tree, at or near the surface of the ground. The larva before pupating cuts a circular flap at the end, making an opening nearly equal to the entire diameter of the cocoon, through which the moth makes its escape by pushing open the door from within.

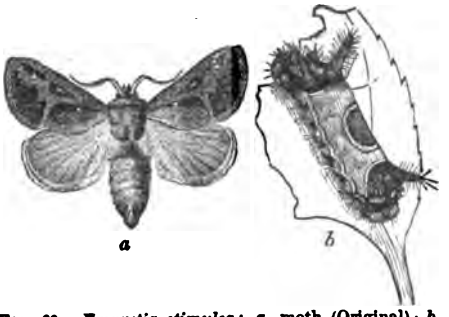


FIG. 60.—*Empretia stimulea*: *a*, moth (Original); *b*, larva (after Riley).

The moth has a wooly body and legs of rich maroon color, with the base of the abdomen and the under wings of lighter brown. The scales of the fore-wing lie flat and have a silken sheen upon the prominent veins and margin, while in the depressions between the veins they stand erect, as in velvet, giving an embossed appearance to the wing. The upper surface of the fore-wing bears several dots of pale yellow, each consisting of a few opalescent scales. The dots are arranged in two pairs, one at the base and the other at the apex of the wing, with a single minute fleck placed half-way between the pairs.

FIG. 61.—*Empretia stimulea*, cocoon. (Original.)

*Parasite.*—The larva is destroyed by a Microgaster.

### THE HAG-MOTH CATERPILLAR.

(*Phobetron pithecium*, Smith and Abbot.)

[Figs. 62 and 63.]

This insect receives its name from the curious hairy appendages which cover the back and project from the sides of the larva, and have a backward twist, like locks of dishevelled hair. These are, in fact, fleshy hooks, covered with feathery, brown hairs, among which are longer, black, stinging hairs. The larva is 15$^{mm}$ ($\frac{6}{10}$ inch) long and has an oval body, over which, however, the flattened and closely applied appendages form a nearly square shield. The cocoon (Fig. 63) is almost spherical, like that of the Saddle-back caterpillar, and is defended by the hairy appendages which the larva in some way contrives to leave upon the out-

side. These tufts give to the bullet-shaped cocoon a very nondescript appearance, and the stinging hairs afford a very perfect protection against birds and other insectivorous animals.

Unlike the preceding species, the Hag-moth larvæ do not seek to hide away their cocoons, but attach them to leaves and twigs fully exposed to view, with, however, such artful management as to surroundings and harmonizing colors that they are of all the group the most difficult to discover. A device to which this insect frequently resorts exhibits the extreme of instinctive sagacity. If the caterpillar cannot find at hand a suitable place in which to weave its cocoon it frequently makes for itself more satisfactory surroundings by killing the leaves, upon which, after they have become dry and brown in color, it places its cocoon.

FIG. 62.—*Phobetron pithecium*, larva. (After Riley)

Several of these caterpillars unite together, and selecting a long and vigorous immature shoot or leader of the orange tree, they kill it by cutting into its base until it wilts and bends over.

The leaves of a young shoot, in drying, turn a light tan-color, which harmonizes most perfectly with the hairy locks of the caterpillar covering the cocoon. The latter is, consequently, not easily detected, even when placed upon the exposed and upturned surface of the leaf.

FIG. 63.—*Phobetron pithecium*, cocoon. (Original.)

The moth has body and legs of purple-brown, with ochreous patches on the back and a light yellow tuft on the middle pair of legs. The abdomen is sable, ending in a tuft of ochreous scales. The fore-wings have the colors of the thorax finely mingled, as in graining. The hind-wings are sable, bordered with ochreous in the female. The fore wings of the male are long and narrow, the hind-wings short and very triangular. Both pairs are, in this sex, partly transparent.

The spread of wing varies in this moth from 20 to 24$^{mm}$ ($\frac{8}{10}$ inch to $\frac{24}{100}$ inch).

### THE SKIFF-CATERPILLAR.

(*Limacodes scapha* Harris.)

[Figs. 64 and 65.]

The generic name *Limacodes*, signifying slug-like, is very appropriately given to this naked and slow-moving caterpillar, which is thus described by Harris: "Body thick, and its outline nearly diamond-shaped; the back is a little hollowed and the middle of each side rises to an obtuse angle; it is of green color with the elevated edges brown. The boat-like form of this caterpillar induced me to name it *Limacodes scapha*, the skiff Limacodes." (Ins. Inj. to Vegetation, p. 419.)

The larva (Fig. 64) lives upon Hickory, Oak, &c., but has been reported as feeding also upon orange leaves. It forms a tough, rounded-oval cocoon. The moth (Fig. 65) is cinnamon-brown; upon each fore-

FIG. 64.—*Limacodes scapha*, larva. (Re-drawn from Harris.)

FIG. 65.—*Limacodes scapha*, moth. (After Packard.)

wing is a large tan-colored spot with a border of silver. It has a spread of wing, in the female, of 30$^{mm}$ (1.2 inches).

The life-histories of the four species of slug-caterpillars are similar, and that given above for the first species may be assumed to apply to each of the others. The same parasites are probably common to them all.

### *BAG-WORMS.*

[Plate XII.]

Worms living in cases made of sticks or leaves, and which they carry about with them from place to place, and enlarge with their growth. Pupæ formed within the the case of the larva. Males issuing as small moths, not differing greatly from others of the same family. Females remaining wingless, degraded forms, to the end of their existence, when they leave the protecting sack, in order to make room for their eggs, and die.

#### THE COMMON BAG-WORM OR BASKET-WORM.

(*Oiketicus abbotii* Grote.)

The baskets of this species are very large, those of the female over two inches long; the sack of the male is, however, only one-third as long as that of the female.

The caterpillar is dirty brown in color. The first three joints, which bear the legs, and are protruded from the case when the animal moves about, are protected by horny shields, and together with the head are mottled and streaked with light and dark brown. When young the case is carried erect upon the upturned end of the body, but as the worm grows larger and the basket becomes heavy with the weight of sticks and fragments of which it is composed, it is allowed to hang down.

The Bag-worm is an omnivorous and most voracious feeder; nothing vegetable appears to come amiss to it, and it sometimes is common enough upon orange trees to do serious damage, especially as it does not confine itself to the leaves, but also gnaws the tender bark of the shoots and cuts off bits of the twigs with which to form its basket. The

basket is differently constructed to suit its surroundings; on oak it is usually formed of bits of rounded twigs, placed crosswise after the fashion of a log-cabin; on trees with dense foliage like the Orange it is oftener fashioned with leaf material. In all cases it is thickly lined and firmly bound together with strong, grayish-white silk, and is too tough to be torn asunder with the fingers. Before the larva becomes a pupa the bag is suspended by a band of silk to a twig or branch.

The winged male escapes from the sack leaving the pupa shell protruding. It is a rather thick-bodied moth of dark brown color. The abdomen is very long, slender, and tapering to the point, which is armed with a pair of shell-like claspers, and these conceal the point of the intromittent male organ. These parts are very elastic and extensile, and enable the male to reach deeply into the sack of the female, in the act of coupling. The fore-wings of the male are rather long and narrow; they are slightly paler than the body, and are marked with a short oblique line, devoid of feathers, and situated just beyond the middle of the wing. The hind wings are short and angular.

The female is without wings or legs, and is, in fact, hardly more than a living egg-sack. When fully mature the pupa splits at the anterior end, and the body of the female protrudes. Without entirely leaving the pupa shell, but dragging it after her, she works her way to the mouth of the basket, where she awaits the visit of the male, having her head at the outlet.

In what precise manner the act of fertilization takes place is not well understood,* but as soon as it is accomplished, the female pushes herself backwards to the farther end of the basket, and, her hinder extremity being still within the pupa shell, she proceeds to fill it nearly full of pearly, cream-colored eggs, packed in silk. The vacant space at the end is then filled with a tangle of floss silk, mingled with feather scales, which the mother plucks from her own body. When finally her body is entirely withdrawn from the pupa shell the lips of the T-shaped slit at the end snap together, entirely closing the exit.

The female continues to work her way slowly outward, weaving as she goes a tangle of silk, mingled with scales stripped from her own body. Having filled the entire space within the basket, and lest she should imperil the safety of her young by remaining in the case to die, the mother completes the sacrifice by dropping from its mouth. Her exhausted body, shorn of its downy covering, falls to the ground, where, naked and defenceless, it becomes a ready prey to ants and other prowlers.

How wonderful an example is here shown of the power of the maternal instinct, which can thus overpower the instinct of self-preservation in an unreasoning insect, and compel her to yield to her offspring, unborn and unseen, a secure retreat, which otherwise in life she never leaves, and from which she could not be torn except piecemeal.

The eggs of the Bag-worm hatch in September. The young larvæ

* See Appendix III.

(Pl. XII, Fig. 2, *a*) push or eat their way out of the pupa shell of the mother, and emerge from the mouth of the basket. They almost immediately begin to form their cases, which they make of any material soft enough to be rasped by their jaws. A bit of cork, for example, is exactly suited to their wants. The process of forming the basket is curious, and, observed under a lens, is as follows: The larva cuts off with its jaws a fragment of cork, of a size and shape determined by the cavity of the mouth; each fragment is, in fact, a mouthful, which the larva ejects and places between its front legs, adding one to another to form a pile, which from time to time it fastens loosely with web. (Plate XII, Fig. 2, *b*.) Pieces are added at the sides until the pile becomes a transverse tangle about as long as the body and placed at right angles to it. Each end of the pile is fastened loosely to the surface on which it rests, and several strands of silk are laid along it from end to end. Then, standing with its body astride of the tangle, the larva bends down its head, and dives under the mass, turning a complete somersault, so that when its head and fore part of the body appear on the other side, the insect lies on its back, bound down by the fillet of silk and bits of cork, which still remain fastened to the surface at the ends. (Plate XII, Fig. 2, *c*.) With a quick movement the larva twists around and stands again upon its feet, having its neck, as it were, under a yoke. (Plate XII, Fig. 2, *d*.) It then makes of the yoke a complete collar by adding bits of cork to each end until the circle is complete. Row after row of fragments is added to this, until the collar becomes a hollow cylinder within which the body of the little workman gradually disappears. (Plate XII, Fig. 2, *e*.) Each fragment as it is ejected from the mouth is fastened by one end to the edge of the band, and secured with a few rapid passes of the silk-producing mouth-organs. From time to time the larva cuts the anchoring threads, shifts its work, and fastens it down again. Like a skillful artisan it works rapidly, not stopping to finish the work as it goes, but only occasionally strengthening it with a few strands of silk on the inside, until the cylinder is long enough to entirely cover its body. One end is then closed up and the inside well coated and finished with a tough lining of silk; the case meantime standing upright and fastened by one end. (Plate XII, Fig. 2, *f*.) When fully completed the larva cuts loose the anchoring cables, and marches off, with the case borne aloft like a cap, on the upturned end of its body. This case of the young larva is constantly enlarged, until it becomes the basket of the adult.

The Bag-worm appears to be single-brooded, and the winter is passed by the young larvæ in their cases. Pupæ are formed late in summer. The males emerge, the females deposit their eggs and perish, and the young hatch during the month of September. Hand-picking must be relied upon to rid the trees of Bag-worms whenever this becomes necessary.

*Parasites.*—The Bag-worm is attacked by an Ichneumonid, ***Hemiteles***

*thyridopterigis* Riley. (Plate XII, Fig. 3.) The females (*b*) are dull red, with banded wings, and are rather more than one-third of an inch (9$^{mm}$) long. The males (*a*) are slender, with black, shining bodies and clear wings; they are somewhat smaller than the females (8$^{mm}$). A number of the parasites inhabit a single case of the Bag-worm, which they partly fill with a consolidated mass of their own dark-brown, parchment-like pupa cases. (Fig. 3, *c*.). The parasites cut their way out through the thick sides of the Bag-worm follicle, each individual apparently making an exit-hole of its own.

Another Ichneumonid, *Pimpla conquisitor* (Say) (Plate XII, Fig. 4), will undoubtedly prove to be parasitic upon this Bag-worm, as it has been bred from other, closely related species, and is a very common enemy of many large caterpillars in the south. It has a rather slender body of black, banded with white, and clear wings. It is about 0.4 inch long. It is a solitary parasite, the female depositing but a single egg in each worm which she stings.

A third and much smaller parasite, *Microgaster* sp., issues late in September from the young larva cases of Oiketicus, in which it spins a snow-white silken cocoon of its own. The parasitic fly is red-brown in color, with dark antennæ and ovipositor. It measures 3$^{mm}$ (0.12 inch) in length, exclusive of appendages.

### NORTHERN BAG-WORM.

(*Thyridopteryx ephemeræformis*, Haworth.)

[Plate XII, Fig. 1.)]

This Bag-worm bears a very close resemblance to Oiketicus, and appears to replace it in the North, where it is particularly injurious to Cedars. It is not certainly known to occur in Florida, but may be found in the northern part of the orange belt. Its case is formed in the same way and its life-history is probably similar to that of Oiketicus. The pupa of Oiketicus is, however, chestnut-brown, while that of Thyridopteryx is dark mahogany in color. The baskets of both species vary in construction, and are not readily distinguished the one from the other. The male of Thyridopteryx is black, with transparent wings.

PARASITES.—Besides the Ichneumonid, *Hemiteles thyridopterigis* Riley, which was first known as a parasite of this Northern Bag-worm, and has been noticed above, several other related parasites are mentioned by authors as preying upon Thyridopteryx.

*Pimpla inquisitor* (Say) (Plate XII, Fig. 5) is mentioned by Mr. Glover as destructive to this Bag-worm. It has a black body, with parti-colored legs; the face is white in the male. Length about one-tenth inch.

*The Yellow-banded Ichneumon* (*Pimpla conquisitor*, Say) (Plate XII, Fig. 4).—This is also a common parasite of the Cotton Worm and other large moths. It closely resembles the preceding, but the joints of the abdomen are ringed with white. It is mentioned by Lintner as one of the

parasites of the Northern Bag-worm.* The species varies in length from about one-quarter of an inch to over half an inch.

In Harris's Entomological Correspondence, p. 242, we find the following: "The parasite of the drop-worm is *Ichneumon concitator* Say, a very common and somewhat variable species, which attacks all sorts of larvæ. It is one of the most common parasites of *Clisiocampa americana*." No mention of this species can be found elsewhere than in Harris's writings, and the presumption is that a confusion has been made between names of similar sound, and that either *Pimpla conquisitor* or *Cryptus inquisitor* was intended.

### THE CYLINDRICAL BAG-WORM.

(*Psyche* sp.)

The cases of a Bag-worm supposed to belong to the genus *Psyche* are sometimes seen upon orange trees; they are not spindle-shaped, as in the preceding species, but cylindrical, and the fragments composing the outside are laid on longitudinally. The fragments usually consist of bits of straw or dead pine-needles, some of which are very long and project beyond or out from the sides of the case. The basket of the female is about 38mm (1½ inches); that of the male 25mm (1 inch) in length, exclusive of projecting points. The female is wingless; its pupa-case is of a light chestnut-brown, and is 15mm ($\frac{6}{10}$ inch) long.

Fig. 66.—*Psyche confederata* G. & R. (After Grote.)

Fig. 66 represents the basket of the male of *Psyche confederata*, with the pupa-shell protruding. (Reproduced from Trans. Amer. Ent. Soc., vol. II, Plate III, Fig. 67.)

The male remains unknown; it is a winged moth, which probably resembles *Psyche confederata* G. and R., but is larger and possibly lighter in color.†

The life-history of this Bag-worm is undoubtedly similar to, if not identical with that of Oiketicus and Thyridopteryx.

### THE ORANGE BASKET-WORM.

(*Platœceiicus gloverii* Packard.)

[Fig. 67.]

A much smaller species than the preceding was first mentioned by Mr. Glover, who gave an account of its habits in the Patent Office

* First Annual Report of the Injurious and Other Insects of the State of New York, by J. A. Lintner, page 84.

† The male of *Psyche confederata* G. and R., is "entirely deep, smoky black. Antennæ plumose. Wings ample, closely scaled, rounded and full. * * * Expanse, 19mm: Length of body, 7mm." The specimens described by Grote and Robinson (Trans. Am. Ent. Soc., vol. II, p. 191) were sent from Texas. Plate III, fig. 67, gives a representation of the basket of this species. Similar cases, which may possibly belong to this species, have been seen upon the Orange in Florida.

Agricultural Report for 1858. Its basket is spindle-shaped, that of the female 18mm ($\frac{7}{10}$ inch), and that of the male 13mm ($\frac{1}{2}$ inch) long. It is covered with finely chopped bits of dry leaf, bark, moss and other scraps, supplemented not unfrequently with the scales of Bark-lice. As an additional protection, several small orange thorns are often fastened to the outside of the case, with their sharp tips projecting backwards and outwards. The pupa case is dark mahogany-brown, and the sutures between the joints are opaque, black, forming on the female pupa three, and on the male pupa four, very distinct rings. The male is a small, dark-brown moth, measuring 16mm ($\frac{64}{100}$ inch) across the extended wings. The female, as in the preceding Bag-worms, is wingless, and undergoes a development similar to that of Oiketicus.

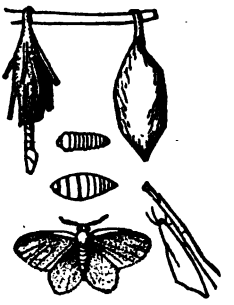

FIG. 67.—*Platœceticus gloverii*. (After Glover.)

UNNAMED BAG-WORM.

[Fig. 68.]

A species of Bag-worm smaller than any of the preceding exists upon Orange, and is not uncommon. Its cases are long, slender, and cylindrical, and covered with fragments of bark, straw, &c.; many of these are linear, and have projecting ends. The female case (Fig. 68*a*) is

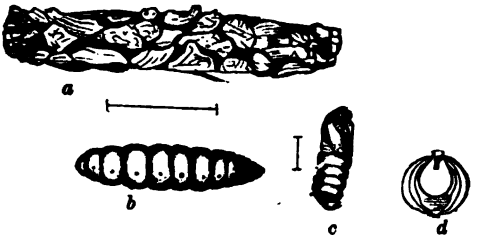


FIG. 68.—Unknown Bag-worm on Orange: *a*, case of female; *b*, pupa of female; *c*, pupa of male; *d* end of male pupa, enlarged. (Original.)

15mm ($\frac{6}{10}$ inch), and that of the male 12mm ($\frac{48}{100}$ inch) long. The pupa of the female (Fig. 68, *b*) measures 8mm ($\frac{32}{100}$ inch) in length. The male pupa (Fig. 68, *c*; *d*, end of pupa enlarged) is very minute, being only half the size of the female. Both are slender, bluntly-rounded at the ends, and of a light chestnut color.

This small species is allied to *Psyche confederata*, by the slender form and light color of its pupa, as well as by the construction and cylindrical shape of its case. In Platœceticus, on the other hand, the fusiform shape and dark color of the case and pupa, indicate a closer relationship to Oiketicus.*

* The species of Bag-worms are more numerous than has been supposed, and several undescribed species are confused in collections with the few species hitherto described.

*LEAF-EATERS WITHOUT CASES.*

ARTACE PUNCTISTRIGA Walker.

The following account of this insect appears in the report of the Commissioner of Agriculture for 1880, p. 252:

"There is occasionally to be found upon the orange a fusiform white silken cocoon, an inch and a half in length. From this cocoon there issues in spring a thick-bodied woolly white moth, the female measuring an inch and three-quarters, and the male an inch and one-quarter across the wings. Each fore wing has five transverse rows of small black dots. We have not seen the caterpillar which spins this cocoon, but from an examination of the cast-off skin to be found at the end of the pupa, and from other facts, we may readily state it to be a rather thick larva, about an inch and a half in length, and covered with long mixed black and whitish hairs, giving it a grayish effect. These cocoons are not confined to orange, but are also found upon the grass at the foot of the tree, and one specimen received was evidently found upon cherry, as pieces of the bark still adhered. The species seems to be comparatively rare, but, as we have said before of other species, it is liable at any time to increase and become injurious; therefore the sooner it is treated of the better. As one of the causes of its rarity we may mention the existence of a large ichneumonid parasite, which we have not been able to breed, owing to the fact that it in its turn is parasitized by a chalcid, of which we have bred thirty-six specimens from a single cocoon, all having made their exit, as usual, from a single hole. It is possible that this chalcid may also be a primary parasite. The specimens were referred to Mr. Howard for study, and decided to be a new species of the genus Encyrtus of Dalman." It was described (*loc. cit.*) as *Encyrtus artaceæ* n. sp.

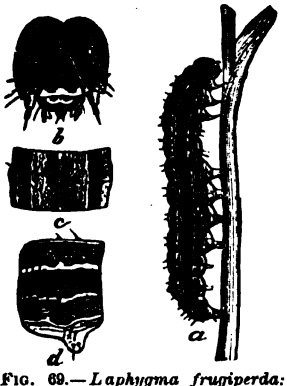


FIG. 69.—*Laphygma frugiperda*: *a*, larva, natural size; *b*, head; *c*, middle joint from above; *d*, do. from side, enlarged. (After Riley.)

THE GRASS-WORM.

(*Laphygma frugiperda*, Sm. & Abb.)

[Figs. 69 and 70.]

Patches of the eggs of this common moth are very commonly found on orange leaves. But although the young caterpillars eat the leaves to some extent, they soon find their way to some other and more succulent food-plant. Full-grown caterpillars are scarcely ever seen upon the Orange, although they can be bred upon it in confinement.

The eggs are dull white, with a pearly luster. The clusters contain a variable number of eggs, and are covered with mouse-colored down from the body of the mother.

The caterpillars grow to the length of an inch and a half. They are very variable in color, the young being dark, sometimes nearly black, and the adults of lighter color, varying from brown to pale green, with fine mottlings of other colors. Several broad stripes of dark and light brown, running from head to tail, render this caterpillar conspicuous and easily recognized.

The moth belongs to the numerous group of Owlet Moths, called in the South "Candle Flies." It has narrow front wings of gray and brown, finely intermingled; and the semi-transparent hind wings of dull white, with smoky margins. Spread of wings about one and a quarter inches.

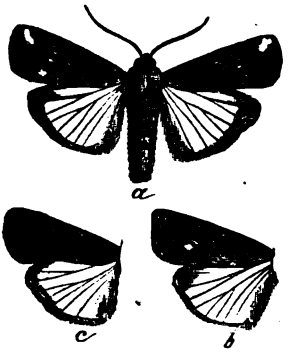


FIG. 70.—*Laphygma frugiperda*: *a*, moth, normal form; *b*, wings of variety *fusca*; *c*, do. of variety obscura—natural size. (After Riley.)

The pupa is polished, mahogany-brown, and is formed in a simple, unlined cell beneath the surface of the ground. The transformations of this insect are completed in one month. There are several broods, but the worms are most numerous in August, and the moths in September.

Orange groves which are kept clean will not be liable to injury from the Grass-worm, which feeds naturally upon grass and succulent herbs. Young groves are sometimes attacked when they are allowed to become foul and only cultivated at long intervals. The amount of damage done by this caterpillar is small, but it may, under special conditions, become a serious pest. Clean culture will in such cases prove an all-sufficient remedy.

### *LEAF-ROLLERS.*

Slender, almost naked, worms, of small size, and usually yellowish-green in color, which roll up leaves, or bind together tender bud-leaves, to form a protecting tube, within which they lurk and feed, and in time transform to pupæ.

Before the moth issues, the pupa is pushed partly out of the tubular shield of leaves. Fig. 71 shows the pupa of *Platynota rostrana* protruding from the side of a folded orange leaf.

The adults are rather small moths, with pointed heads, and oblong, somewhat heavy fore wings, which, when folded, form a roof-like ridge over the body.

The eggs are laid upon the surfaces of leaves, in elongate, oval patches of transparent yellowish-green color. In these patches each egg forms an excessively thin overlapping scale, and the whole mass of fifty to eighty eggs is thus firmly knit together, and can be removed from the leaf without separating. The thinness and cellular structure of the egg-cluster give it a resemblance to certain low forms of vegetable life, and it might readily be mistaken for a mold or a lichen.

## THE CORK-COLORED ORANGE TORTRICID.

(*Platynota rostrana*, Walker.)

[Fig. 71.]

The tubular webs of this species are very common and quite destructive to small seedling and nursery plants, as the worm is apt to select the tender budding leaves at the top of the plant, and by killing these check further growth. Both this and the other Tortricid leaf-rollers do occasional damage to the fruit by puncturing the rind beneath the shelter of a leaf, which they fasten with web to its surface.

FIG. 71.—*Platynota rostrana:* pupa shell protruding from folded leaf. (Original.)

The larva is translucent, dull yellowish-green above, paler on the sides and beneath. The head is brown, and the next joint bears a polished shield of the same color, edged with white. A dark stripe extends along the back, and a stripe of pale brown along each side. The body of the larva is naked, except that each joint bears a few long, fine hairs, each arising from a dot of glistening white. These hairs are sensitive organs of touch. The length of the caterpillar is 18$^{mm}$ ($\frac{7}{10}$ inch).

The pupa is of slender form and chestnut-brown color. It has six pairs of terminal hooks, with which it clings to its tubular web.

The male moths are much darker than the females, the upper wings cinnamon in color, with obliqne bands of umber, and their surfaces much roughened with elevated tufts and ridges of coarse scales. The females are larger and the upper wings much lighter in color, the red being mingled with silver-gray. In this sex the tufts of scales are very minute, and the oblique bands are reduced to fine, elevated lines. Length of the male, with wings folded, 10$^{mm}$ ($\frac{4}{10}$ inch); of the female, 12$^{mm}$ ($\frac{4\,8}{10\,0}$ inch).

The eggs of each batch hatch simultaneously, the last caterpillar quitting its egg-shell a few minutes after the first. The young caterpillars immediately scatter over the plant, but hide in crevices at first, and do not begin rolling the leaves until they are three or four days old. They shed their skins five times during the eighteen or twenty days of their existence as larvæ. They remain eight or ten days in pupa. Allowing eight or ten days for the laying and hatching of the eggs, a period which is not certainly known, a single generation occupies less than six weeks. There are apparently four or five broods during the eight warm months, and an additional brood in mild winters, but the caterpillars may be found at all seasons of the year, and there is in fact very little evidence of a separation into distinct broods.

Hand-picking is the only remedy that can be relied upon, and by this

method young trees can without difficulty be kept free from their attacks.

PARASITES.—*Trichogramma pretiosa* Riley.—This minute Chalcid fly, well known as the parasite which renders effective aid by destroying the eggs of the Cotton Worm, also infests the egg clusters of the Orange Leaf-roller. The mother parasite deposits a single egg in each cell like egg of the Tortrix, and within this narrow cell the young parasite finds food and domicile until it has completed all its changes. Then it eats its way out, making a ragged hole in the shell, and emerges as a perfect four-winged fly like its parent. The fly is 0.3mm ($\frac{1}{100}$ inch) long, clear yellow in color, with ruby eyes and iridescent, hyaline wings, which are delicately fringed with hairs. It has been bred from the Tortrix eggs in March and also in September. Fig. 72 represents *Trichogramma minuta*, a closely-allied species, which differs from *Trichogramma pretiosa* only in color and the form of the small joints of the antennæ.

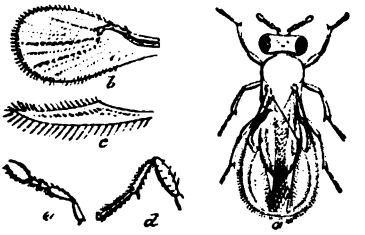

FIG. 72.—*Trichogramma minuta*. (After Riley.)

*Miotropis platynotæ* Howard.[12]—A slender hymenopterous fly has been bred from the larva of the Orange Leaf-roller. It is honey-yellow; head lemon-yellow, with dark eyes and antennæ. The head is much wider than long, and bears above three dark-colored, simple eyelets (ocelli). The wings are hyaline. Three or four maggots of the parasite are found living within a single caterpillar of the Tortrix, which is at last almost completely devoured by them. The parasites form naked pupæ, loosely disposed within the tubular web of the destroyed Leaf-roller, and in about nine days change to adult flies by casting the thin, transparent skin of the pupa. The flies were obtained in September.

*Polysphincta albipes* Cresson.—Cocoons of slightly yellowish, coarse silk, loosely spun, were found by Professor Comstock on an orange leaf, at Rock Ledge, Fla. The flies issued in February. They have been described by Mr. Cresson in the Report of the Commissioner for 1879, p. 208. The body is dull red, smooth and polished; head black, with white mandibles; wings hyaline, and legs white. Length 7mm ($\frac{28}{100}$ inch). This insect is somewhat doubtfully considered a parasite of *Tortrix rostrana*.

*Goniozus* n. sp.;[13] family *Proctotrupidæ*.—A minute parasite is bred from the caterpillar of the Leaf-roller. It has a shining, black body, with yellow legs and antennæ, and hyaline wings, with a dark-brown stigmal spot. Length 2.5mm ($\frac{1}{10}$ inch). Four or five of the parasites are found in a single caterpillar. They spin oval cocoons of whitish silk within the tubular web of the Tortrix. The parasites issued October 1.

### THE SULPHUR-COLORED TORTRICID.

(*Dichelia* [*Tortrix*] *sulphureana*, Clem.)

The caterpillars of this widely-distributed Leaf-roller are very general feeders. In the northern States they are frequently injurious to Clover; in the South the long list of their food-plants includes Cotton, Strawberry, Grape, and Orange; upon the latter they are somewhat rarely found, and it is probable that the thick leaves of the citrus family are not well adapted to the needs of this species. The caterpillar bears a close general resemblance to that of *Platynota rostrana*, but is somewhat smaller, and the head and thorax are pale yellow. The pupa is dark mahogany brown, almost black. The moth is sulphur-yellow above; the upper wings are marked with red-brown, or purple-brown. The markings vary greatly in different individuals, forming a double letter Y or an X upon the folded wings, but are sometimes reduced to a series of dots, representing only the terminal and intersecting points of these letters. The under wings are varying shades between yellow and brown. Length from the tip of the beak to the extremity of the folded wings, 11$^{mm}$ ($\frac{44}{100}$ inch). The life-history and habits of this species in Florida are probably the same as *Platynota rostrana*. In the Report of the Commissioner of Agriculture for 1880 will be found an account of both species. *T. sulphureana* is there said to have three generations in a year in the latitude of the District of Columbia, and probably only one in middle and northern Maine.

### LARGER LEAF-ROLLER.

(*Tortrix*?)[14]

This is a somewhat larger insect than *Platynota rostrana*, from which, however, the larva differs only in minute details. The pupa also is similar to that of *P. rostrana*. The moth is rust-red, with three oblique bands of maroon-red upon the upper wings, and their anterior (outer) edge is sinuate.

The habits of this species are precisely the same as the foregoing, but the larva being larger is more destructive, and often half cuts off small twigs of tender growth, the leaves of which it folds and binds together longitudinally, and feeds without preference upon the wilted leaves within its retreat, or upon the fresh leaves of surrounding branches.

## *WEB-MAKERS.*

### THE ORANGE-LEAF NOTHRIS.

(*Nothris citrifoliella* Chambers.)

The caterpillars of a minute moth have been reported from the extreme southern portion of the orange district, as doing injury in the groves. The following account of it is found in the Annual Report of the Commissioner of Agriculture for 1879, p. 205:

"Specimens of this insect were last summer received from Brevard

County, Florida. We do not know enough of its habits at present to do more than describe it and its methods of work.

"According to Mr. H. S. Williams, of Rock Ledge, the larvæ have been very injurious to the orange trees in his vicinity. They infest the young leaves of the new growth. These they web together by a delicate white silken web, and feed upon the bud, entirely stopping the growth of the shoot. If disturbed, the worm drops by a thread. It is very active, and when removed from its web runs quite quickly.

"The full-grown larva measures about 12mm (½ inch) in length. It is yellowish in color, with the head and first thoracic segment black and somewhat polished. The posterior margin of the black thorax is pale-yellow. The anal plate and legs are polished yellow, with the scattered hairs upon the former blackish; all other hairs are yellow. The first pair of legs is black and the rest yellow.

"When ready to pupate, the larva rolls a leaf around itself and spins a delicate silken cocoon, in which it transforms to a rather stout, dark-brown chrysalis. There is nothing so characteristic about the chrysalis as to merit description. The moths emerged from August 25 to September 5."*

### THE ORANGE WEB-WORM.

(*Anæglis demissalis* Led.)

[Plate XIII, Fig. 1, 1*a*, 1*b*.]

The caterpillars of this interesting little moth are not uncommon upon orange trees, but so remarkably well protected are they by their form, color, and surroundings, that the skill of the collector will be taxed to the utmost in discovering them.

They surround themselves with a tangle of web, involving several twigs and small branches, together with their leaves. (Plate XIII, Fig. 1.) Caterpillars of different ages will be found in each web, which they occupy in joint proprietorship with a small spider. Between this spider and the Anæglis there exists the most perfect harmony. In fact, so close is the association of these allies, that the Web-worm is never seen except in company with the spider, and the webs of the latter are seldom without the presence of the caterpillars.

It must not be supposed, however, that the Web-worm is a mere pensioner upon the bounty of the spider. Both are web-makers; the spider toils by day, its companion is active at night. During the day time the caterpillars remain suspended here and there in the web, and feign death. Their slender bodies, slung in all sorts of positions, are rigidly extended, and the head is bent sharply upwards at the neck, as if in *rigor mortis*. No amount of disturbance can induce the insect to betray

* The original description of the moth will be found in Prof. Comstock's Report (Report of Commissioner of Agriculture for 1879, p. 205).

itself by a movement, and it will even suffer itself to be crushed without exhibiting any signs of life.

The color of the caterpillar—a cinnamon-brown—and its flattened, wrinkled form give it an extraordinary resemblance to a shriveled bit of twig or leaf. The deception is rendered perfect by the presence in the web, whether by accident or design, of dry fragments and petioles of orange leaves which have fallen from the surrounding branches.

In these web-tangles not only the spider lives sociably with others of its kind, hanging their egg-sacks in the net, and raising their young, sometimes in numerous colonies, but two other insects unite in the remarkable confederation, and form for mutual protection a sort of entomological happy family. These are a small tree Cockroach and a coral-red bug (Hemipteron), both of which breed and lurk in the tangles, passing with facility over and between the meshes of the net, and evidently feel perfectly at home there. The bug is, however, known to be a predatory species, and feeds upon the eggs and young of the Mealy-bug (see Chapter VI).

The caterpillar of Anæglis (Plate XIII, Fig. 1, *a*) is long, slender, and somewhat flattened, in color rusty or cinnamon-brown, with a faint tinge of green; beneath, dull green. The body is finely wrinkled and speckled with minute white dots and with a row of bristles on each side, having a large white dot at the base of each. The second joint and last joint of the body paler. Head mahogany-brown. Length, 19 to 20$^{mm}$ ($\frac{8}{10}$ inch).

Pupa clear brown, finely and densely speckled with darker brown, the intermediate shades producing a dark mahogany color; the breathing pores on the sides are prominent and jet-black in color. Terminal point (cremaster) red-brown, furnished with six or eight rather long hooklets. It is usually suspended, like the larva, in a more or less horizontal position in the thicker parts of the web; sometimes naked, but generally with a light, loose tangle of web and bits of excrement gathered about it. The length is less than half that of the larva.

The imago is a dainty little moth, with silver-gray wings, marked with a broad band and several wavy lines of purple-black, and with parti-colored legs. It has the triangular form characteristic of the Pyralidæ sometimes called Deltoides, from the outline assumed by the wings when at rest, which is that of the Greek Δ. The eyes are large, prominent, and black. The rather heavy antennæ curving backwards, and the pointed maxillæ directed upwards like horns, instead of forward in line with the head, give an air of alertness to the insect.

The egg is laid singly upon a strand of the web, either of the larva or the spider with which it is associated. It is spheroidal, pearly, yellowish white, and adorned with a microscopic pattern, consisting of elevated points, from each of which five pairs of raised lines radiate to the five surrounding points.

*Broods.*—As in the case of the Leaf-rollers (*Tortricidæ*), there are many broods during the year. The moths have been bred in February, March, April, June, July, September, and October, and caterpillars of all ages are found at any time during the summer. In December and January, however, only the pupa is obtainable.

*Remedies.*—The extent of direct injury done to the Orange by these Web-worms is slight. It is, however, desirable to remove them from the trees, as the tangles of web harbor Scale-insects, and by protecting them from enemies foster their increase. In many cases Scale-insects will be found to have made their appearance; brought there, in all probability, by the spiders. It is therefore a wise plan to cut away the infested portion, usually comprising only a small inside branch. If this cannot be done without too much mutilation—as, for example, on young plants—after removing the web from the branches they should be sprayed with one of the washes recommended in the treatment of Scale-insects.

## INSECTS OF THE ORDER HEMIPTERA.

### THE ORANGE APHIS.

(*Siphonophora citrifolii* Ashmead.)

[Plate XIII, Fig. 3 *a*, *b*, *c*, and *d*.]

The history of the common Plant-louse of the greenhouse and garden has often been written and, briefly stated, is as follows: In the autumn eggs are deposited singly in sheltered places; from these hatch in the spring only wingless females, which do not lay eggs, but are viviparous and produce young without the appearance of males. During the summer one generation follows another with an astonishing rate of increase; each brood consisting solely of wingless agamic females. Finally, the last brood in the fall consists of winged males and females, by whom the winter eggs are produced and the perpetuation of the species secured in the ordinary manner.

The Aphis of the Orange (Plate XIII; *a*, wingless female; *b*, winged females) is a dark green Plant-louse, from 1.5 to 2$^{mm}$ ($\frac{6}{100}$ to $\frac{8}{100}$ inch) in length, and hardly distinguishable in a popular description from some of the species common everywhere in greenhouses and gardens. It has parti-colored legs and garnet-red eyes. The hue of the body varies with age, from light yellowish-green or rusty green in the very young, to dark green in the adults. The winged individuals are of so dark a green as to have been described as black, and the young of this form are distinguishable at an early age from those destined to remain wingless, both by their darker color and more prominent tubercles upon the upper surface of the body. Two pairs of these prominences gradually develop into wing-pads, and after the final molt become well-formed and transparent wings.

The development of this southern Aphis differs from that of its northern congeners, in that the winged and the wingless individuals occur together at all seasons, and both forms produce their young living. The males remain undiscovered, and it is entirely possible that they rarely make their appearance, perhaps only at intervals of several years. In the warm climate of Florida the cold is never sufficiently severe to kill winged females, and the Orange not being deciduous a supply of food is nearly always at hand. A winter egg is not, therefore, a necessity, as in the North, and it may be that none are deposited in ordinary seasons. The late fall broods consist in great part of the winged females, while in spring, and especially in midsummer, the wingless form predominates.

In the act of birth, the hinder end of the young Aphis appears first. The young is slowly protruded from the body of the mother, until only the tip of the head remains unexpelled. During the process and for a few minutes after, all motion outwards ceases, the larva remains immovable and with its members rigidly applied to its body. Soon it disengages first one leg, and then another, until all are widely extended. The antennæ are then raised and brought forward. This movement severs the contact with the mother, and the new-born young drops upon its feet, in the full possession of its faculties (which it makes no delay in putting to the test). Within ten minutes from the time when its expulsion from the mother began, it is quietly feeding by her side, its sucking beak inserted in the tender tissues of the leaf, and its body rapidly becoming distended with the juices of the plant. In less than a week after its birth, the plant-louse has become adult, and begins in its turn to produce young.

*Destructive powers.*—The Orange Aphis attacks the tender new growth; it checks the growth of young shoots, and curls the tender leaves. With such a direct and rapid method of reproduction, and with a winged form of female ever present to spread the pest, it will be seen that this insect presents a truly formidable aspect as a destroyer. Were it not held in check by numerous enemies and parasites, it would soon ruin the trees by destroying the new growth, and render the culture of the orange for profit an impossibility.

*The work of enemies.*—Such, however, is the activity of its enemies that not a single individual Aphis escapes destruction, or is allowed to exert to the full its reproductive powers. Colonies rarely attain great size, and, in fact, are frequently exterminated in their very beginning, and before any appreciable injury has been done.

*The parasite.*—The principal agent in accomplishing this result is a parasite, whose larva, feeding internally upon the Plant-louse, finally kills it. In dying the body of the Aphis becomes distended to the utmost, assumes a globular shape, and turns to a dingy yellow color. In drying it adheres firmly to the plant. (Plate XIII, Fig. 3, *c*.)

Within the body-cavity of its victim, the space within which it nearly

fills, the larva of the parasite, a little, white, footless grub, lies concealed, curled up, with its head touching its tail. In a few days it becomes a pupa, and six or seven days later it emerges through a large hole eaten in the dry shell of the Aphis, as a slender, black, wasp-like fly, with yellow legs. This fly is, of course, very minute, being $\frac{7}{100}$ inch in length. It is *Trioxys testaceipes* Cresson.* (Plate XIII, Fig. 4.)

Its work can always be seen where the Orange Aphis has been colonized for a week or more, in the numerous bloated remains of the Aphis, some of which may still contain the parasite, and others exhibit the round hole through which it has made its exit. (Plate XIII, Fig. 3, *c* and *d*.)

Although only a single fly is bred from each individual of the plant-louse, the numbers of the parasite increase more rapidly than those of its victim, and as every Aphis is in time parasitized, no colony long escapes extermination. Were it not for the facility with which new colonies can be started at a distance, through the flight of the winged females, this species of Aphis and some others which are similarly attacked would suffer complete extinction in a single season.†

*Other enemies.*—Numerous other enemies combine to thin the numbers of Plant-lice. Those which have fallen under observation as destroying the Orange Aphis are discussed in the chapter on Predatory Insects. Among the number are three species of two-winged flies (*Diptera*), whose larvæ subsist exclusively upon Plant-lice, and several species of Lady-birds (*Coccinellidæ*) which, both as larvæ and as perfect beetles, rely to a very great extent upon this source for their food supply.

*Remedies for Aphis.*—Moderately strong applications of whale-oil soap, or the kerosene washes recommended for Scale-insect, are perfectly effective in killing the Orange Aphis, and will not injure the young growth upon which they are found.

### THE GREEN SOLDIER-BUG.

(*Raphigaster hilaris*, Fitch.)

[Fig. 74.]

A large green Plant-bug is sometimes observed to suck tender shoots of Orange, causing them to wither and die. The same insect is, to a certain extent, predaceous, and has been reported as sucking Cotton Worms and other insects, for which reason it has usually been classed among beneficial insects. The full-grown bug is bright green in color, with a very fine yellowish line around the entire margin of the insect, and a black dot at the outer angles of each abdominal joint. The form

* Described in Report of the Commissioner of Agriculture for 1879, p. 208.

† Mr. Ashmead has described another minute, black parasite, which he bred from the Orange Aphis, and to which he gives the name *Stenomesius* (?) *aphidicola*. (Orange Insects, p. 67.) Three of the flies issued from the body of a single Aphis, and it may be a secondary parasite, preying upon the Trioxys.

is broadly oval, the legs slender and of the same color as the body. Length, 17$^{mm}$ ($\frac{68}{100}$ inch).

The following account of ravages committed by the Raphigaster is from a correspondent in Florida. It affords a good example of the sudden rise into importance as a pest of an insect which is ordinarily a quite insignificant enemy of the Orange.

FIG. 73.—*Raphigaster hilaris.* (After Glover.)

* * * "You also request observations on the Green Soldier-bug. I forward by same mail twigs of the orange tree injured by the bug. The insects are coupling now. The females will soon lay the eggs in a cluster on a leaf, straddling over them while laying. The young appear in the latter part of February or the first part of March. As observed by the eye the young are black, with white spots, which color they retain until nearly full grown, when they acquire wings and change to a bright green. How this is done I do not know. They mature very quickly, and increase with surprising rapidity, continuing to breed until November. In the spring and early summer they confine their attacks principally to garden vegetables and succulent weeds. They are particularly abundant on tomato-vines, egg-plants, turnip-tops, and mustard, seldom doing much damage to orange trees at this season. When pea-vines are well grown, about or a little before the time of blossoming, they abandon nearly everything for the pea-vines. Last year they totally destroyed my garden. Not one tomato came to perfection. Where the insect had inserted its sucking-tube a reddish-yellow spot appeared. When cut the fruit was full of lumps and totally devoid of flavor. The tomato-vines grew so enormous a crop that the ground was almost covered by the fallen fruit. Last year I had 35 acres planted in cow-pea vines, which bore an enormous crop of peas; but not enough sound peas could be gathered to plant 5 acres additional land. Later it was impossible to find a sound pea. I attempted to turn under the vines, but so luxuriant was the growth that it could not be done. Towards the end of August the pea-vines were dead or dying, when the bugs swarmed to the orange trees, killing nearly all the new growth. Immense numbers were killed by keeping men constantly going over the grove, shaking the trees, and killing all that fell on the ground. The wingless individuals were readily killed, but the larger number of the mature insects saved themselves by flight. This method of destruction was kept up until the middle of December, by which time very few were found. On very cold days the winged insects were nearly dormant and could not fly. I have the trees frequently searched now, but rarely find the bug. The number of the insects is incredible. When thoroughly shaken, the ground under the trees would be alive with the fallen insects, and two days later just as many would be found. I despaired of getting rid of them until the cold weather commenced,

when I found the number rapidly decrease until their nearly total extinction.

"As to the damage. The bug first attacks the latest growth, which wilts and droops while the bug is sucking; in a few days the shoot is dead; the same eye soon sends out another shoot which shares the fate of its predecessor, and so on until the eye has the appearance of a large bunch, as you will see on twigs sent. After all the tender growth has been destroyed the bug inserts his sharp sucking tube in the previous growth which has nearly hardened. Here I can only give you the facts and my theory; it is a fact that the insect sucks such wood, but the damage does not follow so quickly; but very soon after, on such wood known to be sucked, numerous bumps appear, which crack and exude a sticky sap, white at first, but soon a rusty red, and hard. Later on the insects suck the juice from fully-matured wood (an inch or more in diameter); on this wood the bumps do not appear, but the same kind of sticky sap exudes in tears, which soon harden and redden and are what I understand by "red rust." That the cause and effect are strictly true I can only surmise, but this much I and my men have seen: the insects sucking the sap as stated and the branches where sucked having the appearance described. In the winter months I have found clusters of the bugs on the stocks of the buds, two inches in diameter, and always an exudation of sap at these places, which I have never observed to redden as in the instances stated above. Why this is so, and why the insect leaves the more tender bud above to suck the sap from harder wood nearer the roots, I can offer no suggestion. At first I was strongly inclined to think that red rust was caused by soil-poisoning, but if so, why is it that trees have grown for so many years on the same soil and never had this disease until the introduction of the Green Bug? To illustrate: When I bought this place ten years ago there was a field of five acres which had been in partial cultivation several years, and on which grew spontaneously the tomato and mustard plant, the two plants on which the insects thrive the best. (At present I can only find the insect on the mustard.) Since my purchase I have kept this field constantly growing pea-vines, as well as the forty other acres which I have in orange trees, thus giving every encouragement to the increase of the pest. Adjoining this old field was a wild orange grove in a dense forest. Many of the sour stumps had large sweet buds, neither the buds nor sour trees giving any signs of the red rust until the winter following the clearing, and after a crop of pea-vines had been grown among the trees. Now the trees in this wild grove are just as much damaged as in the old field adjoining. Another case I will mention, and not trespass further on your patience. Five miles distant is the grove of L. Merritt, a wild grove budded. The buds are six years old and ought to be bearing heavy crops, but an occasional bloom is all. The trees have been in an unhealthful and "die back" condition for several years. When visiting his grove in the fall of 1881, I told him I had

some trees in the same condition and was inclined to think the Green Bug was the cause. Since that time he has persistently hunted the bug, whipping it out of the large trees with poles, and killing wherever found; also he stopped planting peas. I have just visited his grove and found but two twigs damaged, and could not find a specimen of the bug. The trees have changed so remarkably in this grove that it was past recognition. Instead of a dense crop of dead twigs all over his grove, as at a previous visit, the trees had nearly doubled in size, and had a very large, healthy growth of branches in place of the dead twigs. I hear his trees are now in profuse bloom. I do not think that washes will do much damage to the bug. Very strong whale-oil soap rarely kills. Whale-oil soap, 1 pound; kerosene oil, 1 pint; water, 12 pints; sometimes kills when sprayed over them, nearly always when immersed. Pure kerosene kills, but not always instantly.

"The Green Bug has a parasite. I do not know what, but I frequently find their shells with the inside devoured. Last winter I buried a number to see if plowing under would kill them. In ten days none were dead; in three weeks 20 per cent. were dead, nothing remaining but the shells; in six weeks all but one were dead, empty shells remaining. The living insect I put in a bottle with a little earth over it, hoping to find the parasite, but unfortunately in about ten days the bottle was broken, the Green Bug was dead, the shell empty as in the other instances.

"At present the insect is very rare here; if found at all, generally on the mustard plant or weed locally known as nightshade. Yesterday, while showing a lemon tree to some visitors, I found some of the twigs drooping and remarked it looked like the work of the Green Bug. One was found under a leaf close to his work. I send you one of the shoots. If at any time you may consider the subject of suffiient importance to send a trained observer in the field, I will be happy to see him here and place every facility at his disposal."—[JAMES FRANKLIN, *West Apopka, Fla., January* 31, 1883.

FIG. 74.—*Metapodius femoratus.* (After Glover.)

### THE THICK-THIGHED METAPODIUS.

(*Metapodius femoratus*, Fab.)

[Figs. 74 and 75.

A large dark-brown bug, emitting an unpleasant odor when handled, is addicted to sucking the juices of the Orange, attacking either the succulent shoots, the flowers, or the fruit. It has a heavy, clumsy body, with projecting angles to the thorax; the thighs of the hind pair of legs are swollen and spiny, and the shanks of the same pair are flattened with jagged edges. The adult bug is nearly one

inch long. Although sluggish in habit, it takes wing when disturbed, and flies heavily with a loud, buzzing noise.

The eggs have the form of an oval casket, triangular in section, and are quite large; 3$^{mm}$ ($\frac{12}{100}$ inch) in length. They are laid singly upon the leaves of plants, and are very beautiful objects, opalescent, and gleaming like a drop of molten gold. Figs. 76 *a* and *b* show the egg with the exit hole of the larva.

FIG. 75.—Egg of *Metapodius femoratus*. (Original.)

The young make their exit through a large hole eaten in the end. The young bugs are brightly variegated with red and black, and their bodies bristle all over with spines. They grow more somber in color with each casting of the skin, and gradually approach the adult in form and color.

## OTHER SUCKING BUGS.

***Metapodius terminalis*** Dallas.—This species can, with difficulty, be distinguished from the preceding, and the same account may be given of its life and habits. Both species of Metapodius vary greatly in size, but *M. terminalis* is usually the larger and heavier of the two. *M. femoratus* is the commoner species in the cotton-growing States, and *M. terminalis* is more abundant in the orange districts of Florida.

Like the Green Soldier-bug (*Raphigaster hilaris*), the species of Metapodius are known to prey upon other insects, particularly upon caterpillars, which are filled with the juices of plants, and there may be often a doubt as to whether they are injurious or beneficial.

***Euthochtha galeator*** (Fab.). (Fig. 77).—This is another foul-smelling bug, having the general shape and appearance of Metapodius. It is however a smaller and lighter-colored insect; and the shanks of the hind legs are slender. The color is rusty-brown, and the length of the adult insect is 16$^{mm}$ ($\frac{64}{100}$ inch).

FIG. 76.—*Euthochtha galeator*. (Original.)

The eggs of *Euthochtha galeator* resembles those of Metapodius, but are only one-third as large, and are laid in irregular clusters on leaves or stems of plants. Their color is a ruddy gold.

The young bugs are purple-black, with orange heads and crimson abdomens. Their bodies are very spiny.

The habits of this bug do not differ from those of Metapodius. It is a very common and often a very destructive insect.

Other species of plant-sucking bugs will be found doing occasional damage to tender growth on Orange, but the above are the largest and best known of this class of offenders.

# CHAPTER XI.

## INSECTS AFFECTING THE BLOSSOM AND FRUIT, AND SCAVENGER INSECTS.

### INSECTS AFFECTING THE BLOSSOMS.

During the season of blooming, insects of many species are seen flitting about the trees, attracted thither by the fragrance of the blossoms, and feeding upon the nectar, which they secrete in abundance. The greater number of these visitors are not only harmless to the plant, but are even of the greatest service, in securing the fertilization of the flowers, which could not otherwise be accomplished.

In fact, it is a fair inference that its fragrance and its sweets serve no other purpose in the economy of the flower than to call to its aid friendly insects which, in their restless movements from flower to flower, bear with them and distribute widely the fertilizing pollen dust.

A few injurious insects, however, frequent the blossoms. These are all sucking-bugs, and they cause the buds to blast and the flowers to fall prematurely, by tapping the juices from their stems and other parts. Among the most injurious are the Green Plant-bug, *Raphigaster hilaris* Fitch, mentioned in the preceding chapter, and the Leaf-footed Bug, *Leptoglossus phyllopus* (Linn.), an insect which will be considered among those especially injurious to the fruit.

#### THRIPS TRITICI (?) Fitch.

[Fig. 77.]

By far the most common insect found in orange blossoms is a little yellowish bug, whose slender body measures but $1^{mm}$ ($\frac{1}{100}$ inch) in length. The color of the eyes is dark red or brown; all the other parts are clear honey-yellow. The adults have narrow wings fringed with hairs. These hairs are characteristic of the family, and replace the membranous parts of the wing of most other insects.

Notwithstanding the rudimentary structure of their wings, these insects are capable of active flight, and they also have the power of leaping.

The Orange Thrips inhabits all sweet-scented flowers. In Lilies and Roses, as well as in orange blossoms, they sometimes swarm in countless numbers, and do great damage whenever they become unduly abundant.

From orange blossoms they are seldom wholly absent. They appear however to feed for the most part upon the stamens and petals, from

which they suck the bland and fragrant oil. In the Orange, these parts of the flower are naturally deciduous, and the effect of the attacks of the Thrips is to hasten their fall; for the most part leaving uninjured the fruit-producing pistil, which moreover will not fail to have been fructified with the pollen which these active midgets distribute over every part. Figure 5 on Plate XI shows an orange blossom infested with these insects. The Orange, being a profuse bloomer, commonly sets more fruit than it can mature, and is constantly throwing off the surplus from the time when the buds begin to open until the branches are relieved of their burdens at the harvest. A large share of the energy of the tree is expended uselessly in the fruit which falls to the ground prematurely, and is lost.

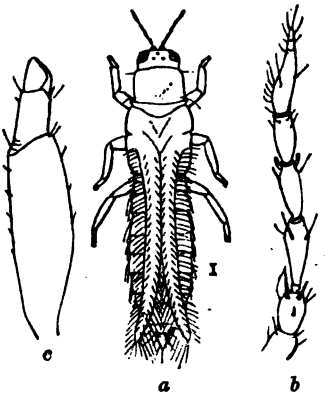


FIG. 77.—*Thrips tritici*: *a*, Thrips enlarged, drawn from living specimens; *b*, antenna; *c*, leg, much enlarged. (Original.)

The operations of the Thrips are confined to the flowers and therefore tend to anticipate and prevent this waste, by thinning out the superabundant bloom at the outset. For this reason the insect is more often a friend than a foe to the plant, and were it not for the fact that its numbers sometimes increase inordinately and to such an extent as to effect injuriously the forming crop, it could not be classed among the insect enemies of the Orange.

The Orange Thrips is frequently an annoyance to persons occupied in flower gardens where Lilies and Roses are in bloom. It settles upon the hands and face, and bites sharply, although without poisonous irritation.

*Remedies.*—A moderately strong solution of whale-oil soap, one pound to four or five gallons of water, will suffice to destroy this insect if sprayed upon the flowers in fine spray. Applications of pyrethrum will also effectively reduce their numbers. It is best used in liquid, delivered in fine spray upon the flowers. One ounce of the powder in each gallon of water is sufficient to destroy the Thrips. The powder must be kept suspended by frequent agitation of the liquid.

## INSECTS AFFECTING THE FRUIT.

### THE COTTON STAINER OR RED BUG.

(*Dysdercus suturellus* Herrich-Sch.)

[Plate XI, Fig. 4.]

This Soldier-bug, well known to cotton-growers in Florida, as occasioning great loss by puncturing the cotton bolls and injuring the fiber, has recently been found destructive to oranges by puncturing the rind

and causing the fruit to drop from the trees and rot rapidly. Attention was first called to this new habit of the bug by letters to the Department of Agriculture from South Florida, in December, 1879. Since that time numerous reports have been received of excessive injuries done, especially in cases where cotton is raised among or in close proximity to the orange trees.

The Cotton Stainer may be distinguished from all other Soldier-bugs, some of which resemble it superficially, by its rather oval form, deep coral-red color, and white markings, which form a collar-ring behind the head, and a border upon each joint of the body. The wings of the young are mere pads of black color, but in the adult they cover the body, and are crossed with narrow lines of white, forming the shoulder-straps, from which these insects take the name "Soldier-bugs."

*Broods, Habits, &c.*—There are many broods during the warm months and even in mid-winter the young may often be found.

The principal food of the bug is the oil of cotton seed, to obtain which it punctures the hard seed-coats. It also feeds upon the seeds of other Malvaceous plants, although the precise species attacked have not been ascertained. In winter the Red Bug may be found gathered in vast numbers upon the heaps of waste cotton seed about the gin houses.

The eggs are oval in shape, amber-colored, with a pearly luster, and present, under a lens, a pattern of closely reticulated lines. They have been sent to the Department of Agriculture from the Indian River, Fla., in April, "laid in a group of twenty-one upon the under side of an orange leaf."* That this disposition of the eggs is normal may be somewhat doubtful. In winter at least, and around gin houses, the eggs are dropped loosely in the sand, and among the heaps of cotton seed upon which the bugs are feeding.

*Attacks upon the Orange.*—In January and February, if the weather is mild, the Red Bugs desert the fields where they have lingered upon the dead trash and waste of the cotton, and suddenly make their appearance in the orange groves. Usually this takes place only in groves adjoining fields that have been planted in cotton, but, as they are strong flyers, the bugs not unfrequently migrate in considerable numbers to a distance even of several miles.

At first, only adults are seen; these at once attack the fruit upon the trees. A week or ten days later, the wingless young appear; always upon the ground, clustering upon the fallen fruit. If the trees are not stripped and the fruit harvested before the young brood become adult and acquire wings, the entire crop will be lost. Even the packing-house is not safe from invasion, and fruit is apt to be destroyed after it has been gathered and stored in the bins.

In puncturing the orange, the bugs insert their slender sucking beak, often its entire length, and although the oil of the rind forms their principal food, they, nevertheless, frequently regale themselves with

* Report of the Commissioners of Agriculture for 1879, p. 204.

draughts of juice from the pulp within, and are sometimes seen to suck the juices from the surface of split or injured fruit, tapping it with the tips of their probosces, after the manner of flies.

The sucking-tube, having the fineness of a hair, leaves no visible wound upon the outside of the fruit, and within no indication of its passage. An orange which has been attacked therefore shows no outward sign of injury; nevertheless, a single puncture causes it to drop in a few hours from the tree, and to decay in one or two days

It is quite useless to pack for shipment to a distance the fruit from a grove which is attacked by Red Bugs, since the unsound fruit decays in the packages and soon ruins the whole.

*Geographical distribution.*—The Cotton Stainer is an inhabitant of warm climates. It is found in great abundance in the Bahamas, where, according to Mr. E. A. Schwarz,* it annually destroys a large part of the cotton crop. From the Bahamas or other West India islands it may have been introduced into the extreme southern portions of the cotton belt, in the United States. In Florida it has not been reported as occurring north of Gainesville, in Alachua County, and it is unknown to cotton-planters in the northern part of that county, although a familiar insect in cotton fields everywhere south of Gainesville.

The taste for oranges appears to have been recently acquired. Mr. Glover, in the Agricultural Report for 1875, gives an account of the insect and its depredations upon cotton, but does not mention it among the insects noted as injurious to the Orange. It should, however, be remarked that at the date of Mr. Glover's observations comparatively few bearing orange groves existed in the more southern portion of the State.

In 1879 the insect first attracted the attention of orange-growers, and the crop of that year was injured by it in several widely separate portions of the fruit belt. In various parts of the State it has since become a well known and much dreaded pest, and has occasioned very serious losses.

*Freedom from Attacks of Enemies.*—The Red Bug is one of those showy insects which are probably possessed of an acrid flavor, disagreeable to other animals, and are in consequence not much preyed upon by enemies. Certain it is that the Red Bug is not eaten by fowls or other birds, nor has any enemy of its own class been hitherto observed to attack it. The eggs will very probably be found to have parasites, as is the case with most other Hemiptera, but none have as yet been discovered

*Remedies and remedial Measures.*—In default of aid from predatory animals it remains for man alone to combat this pest. Its extermination, in view of its gregarious habits, would not be a matter of great difficulty, if concerted action over wide areas could be secured. As was

*Report upon Cotton Insects, Department of Agriculture. 1879. Appendix I, p. 347.

long ago suggested by Mr. Glover, in his report above mentioned, the bugs may be attracted to small heaps of sugar-cane trash, with which Paris green or some other poison should be mixed; or the bugs, when collected upon piles of cotton seed in winter, may be destroyed by drenching them with boiling-hot water. The experience of several cotton-planters with this last method has shown it to be practicable, but to be effective it must be thoroughly carried out. As the eggs cannot all be reached and destroyed by the hot water, the operation needs to be repeated several times at such frequent intervals that the bugs are not allowed to reach maturity and deposit fresh eggs.

In the orange grove effective traps may be made with refuse oranges, orange peel, &c., and the bugs, when thus collected, may be destroyed with the kerosene washes used for Scale-insects. The kerosene solutions will also be more effective than hot water in reaching and killing the eggs.

The Red Bug can never become permanently attached as an enemy to the orange tree, since the fruit which alone supplies it with food lasts only a few weeks, and during the balance of the year the insect must seek its subsistence elsewhere. It is therefore an enemy to be dreaded only in the vicinity of cotton fields and gin houses, in districts where cotton is largely planted, or lastly, and with less probability, in case thickets containing numerous wild Malvaceous plants furnish the bugs with a supply of food during the months when the Orange is not in fruit.

In South Florida, at least, the planting of cotton in the vicinity of orange groves will necessarily be abandoned. Throughout the orange district the acreage planted in cotton has never been large, and it is for many reasons likely to diminish rather than to increase. With the abandonment of cotton planting, the Red Bug may be expected to disappear from this region.

### THE LEAF-FOOTED BUG.

(*Leptoglossus phyllopus* Linn.)

[Fig. 78.]

This is a chocolate-brown bug, three quarters of an inch in length. It has the shanks of the hind legs very broadly flattened, and the edges jagged, resembling a tattered leaf fragment; hence its popular name. The markings, a white bar across the folded wings, and a small spot of the same color on each of the leaf-shaped shanks, are very characteristic, and render this species easily distinguishable among other bugs of the same family. The young bugs, with undeveloped wings, show the brighter red color of the body, and do not acquire the peculiar flattened hind shanks until nearly adult.

The eggs are golden brown in color, and are laid in a single row or chain, along a stem or the leaf rib of a plant. They are cylindrical,

flattened on the under side and at the ends, and are closely applied end to end, forming a stiff, cylindrical rod in which each egg appears as a joint or cell. The young issue through a large hole eaten in the upper side of the egg.

The normal food of this bug in the South is a large Thistle, upon the heads of which young and old may be found clustering and sucking the juices of the plant. The young bugs are rarely found in Florida except upon the Thistle, or similar succulent plants, but the adult bugs, being strong on the wing, make excursions to very great distances, and enter the orange groves at the time of blooming, to suck the opening buds or tender shoots. Again they may be found attacking the ripening fruit, and causing it to drop in consequence of their punctures. The damage done in this way is often very considerable, and in some reported cases has amounted to an almost total loss of the crop.

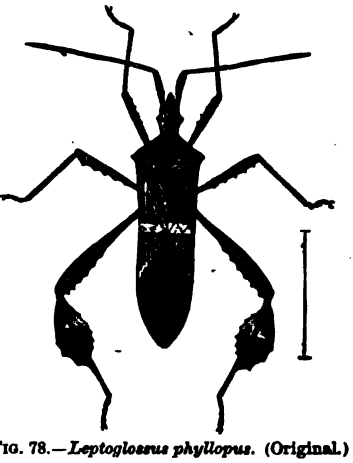

FIG. 78.—*Leptoglossus phyllopus.* (Original.)

Like many bugs of this family, they are particularly active in hot weather, and it is then very difficult to get within reach of the adult insects, as they take wing readily and fly away. But in cool or cloudy weather they are more sluggish and may easily be found and killed by hand-picking, or by knocking them into a bag or net with a stick.

Where Thistles are abundant this bug is sure to prove a serious pest, as the Thistles form a propagating ground from which they spread to a distance. A single large patch of Thistles has been known to infect a wide area, but when these were cut down and destroyed, the bugs in time disappeared from the groves in the neighborhood and gave no further trouble.

## THE MEXICAN FRUIT WORM.

An unknown worm, of perhaps an inch in length, is said to be very destructive to oranges in Mexico. It penetrates the fruit to the core, and feeds upon the pulp, both fresh and after it has begun to rot in consequence of the attack.

A few years ago a very large percentage of the oranges sold in the markets at Vera Cruz contained these worms, and were entirely uneatable. It is said that no mark upon the outside of the fruit reveals the presence of the worm within.

In the absence of any definite knowledge in regard to this insect, it is only possible to point out the danger of its introduction first into the

groves of Louisiana and then into Florida by means of oranges imported from Mexico at the port of New Orleans.*

## SCAVENGER INSECTS.

### *INSECTS FEEDING UPON DEAD WOOD AND BARK.*

#### TREE-INHABITING ANTS.

Several species of ants which live in trees make their nests in the dead wood of the Orange, more especially in twigs and smaller branches which have been killed by frost. The wood of these winter-killed shoots being corky and easily excavated, they are frequently hollowed out by ants, and serve as places of deposit for their eggs and young.

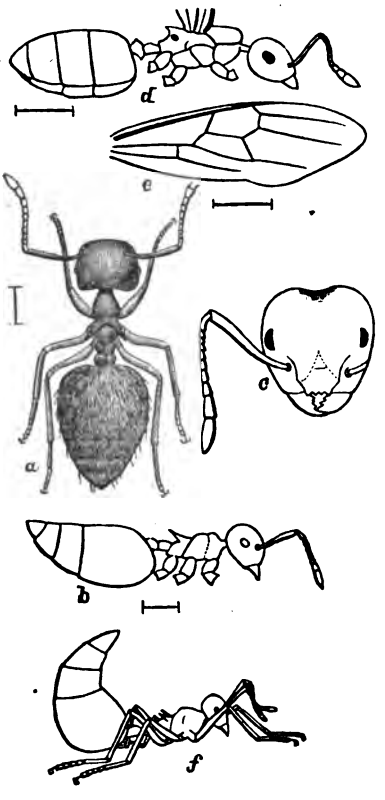


FIG. 79.—*Cremastogaster lineolata*: *a*, *b*, worker major; *c*, head of do.; *d*, female; *e*, wing; *f*, worker minor. (After McCook.)

*Cremastogaster lineolata* (Say). [Fig. 79.] This is one of the commonest of the species which have the above habit. It is jet-black, shining, and has a broadly triangular abdomen, which it elevates in a threatening manner when excited.

The species is very abundant upon Oak and other forest trees. It attends the various honey-producing insects found upon trees and feeds upon their honey-dew without doing any violence to the insects themselves. Its presence upon the orange tree, therefore, is of very slight importance either for good or evil.

Other species of ants which have been observed to make their nests in orange twigs probably have the same habits, and if not positively beneficial, certainly do little harm to the tree, and none of them gnaw or do injury to the growing parts.

*An Australian moth, *Ophideres fullonica* (L.), is said to pierce oranges with its proboscis and suck the juices of the pulp. In an article entitled "Les Lépidoptères à Trompe Perforante, Destructeurs des Oranges," M. J. Künckel describes and figures the proboscis of this insect, and shows its special adaptation to this end. (Comptes Rendus des Séances de l'Académie des Sciences, Paris, 30 Août 1875.)

### THE ORANGE SAWYER.

(*Elaphidion inerme* Newman.)

insect has been described in Chapter VIII, and is there shown to rious, under a careless sys- pruning, in which the ends aches are left untrimmed, nfficient dead wood to at- he parent beetle, but not to support the larvæ; so e latter are driven by hun- enter and feed upon the liv- od. It appears, therefore, ıder natural conditions this s merely a scavenger. Its eds upon the wood of many ınd, like most members of ıgicorn family, thrives only iseased and devitalized tis- upon wood which, though as not entirely parted with and become hard and dry. 80 represents the larva of *llelum*, a closely allied spe- ving the same habits as the Orange Sawyer, but which lives in , &c.

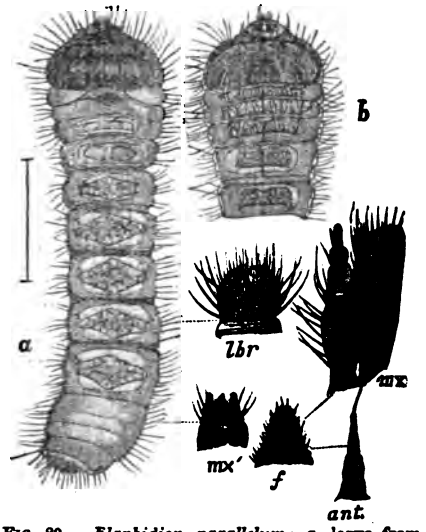


FIG. 80. — *Elaphidion parallelum*: *a*, larva from above; *b*, from beneath; *f*, ligula-like process, behind the labial palpi; *lbr*, labrum; *mx*, maxilla; *mx'*, mentum; *ant*, antenna. (After Packard.)

### THE ORANGE FLAT-HEADED BORER.

(*Chrysobothris chrysoela* Ill.)

[Plate XIV, Fig. 8.]

twigs and branches of Orange are frequently found, upon which k is cracked and loosened, so that it comes off at a touch, bring- ay with it considerable dust from the wood lying immediately ı, a thin layer of which has been reduced to powder. When the ark and sawdust are removed, the surface of the branch presents led appearance, indicating the path of an insect. The edges of ck form a succession of semicircular curves, as if made by the sweep iniature scythe. It is, in fact, the gallery of an extremely thin- grub or sawyer, made partly in the bark and partly in the wood, ways filled with comminuted wood, which has passed through the ve organs of the grub, and has been voided and deposited be- as the insect made its way through the wood. The cell in which pa is formed is excavated in the solid wood. It lies parallel with neath the gallery, with which it is connected at one of its ex-

tremities. The short passage connecting the pupa-cell with the gallery is carefully filled with wood dust, firmly packed in place, so that even when the bark is removed and the gallery exposed to view, the mouth of the cell remains concealed, and is only disclosed upon the exit of the beetle. The cell is then found to be broad and shallow, oval in outline, and lined with a silken layer that is almost invisible by reason of its delicacy.

*The Beetle.*—In spring or early summer there issues a very handsome little beetle, broadly oval in form, and about $8^{mm}$ ($\frac{32}{100}$ inch) in length. The colors of the body are metallic bronze, greenish below and purple above. Upon the wing-cases are ten large spots of brilliant emerald green.

*The Larva.*—The form of the larva is characteristic of the family. It has the second joint greatly enlarged, forming a broad, flattened disk, into which the first joint and the small head are sunken, only the black tips of the jaws appearing beyond the cleft in the anterior border. The succeeding joints form a tail-like body, which is less than half as wide as the enlarged joint. In life the body is usually curved strongly to one side or the other, giving it still more the appearance of an appendage. The large joint is covered upon both of its flattened faces, with minute, horny denticulations, which serve to hold the body firmly against the smooth walls of the burrow while the jaws are forced into the wood.

The body of the lava is naked, or with scattered and nearly invisible hairs, soft, white, and without legs. It moves but slowly in its gallery, and only by means of the contraction and expansion of the enlarged flattened joint.

The pupa presents no especial peculiarities, and merely outlines the form and members of the perfect beetle.

*Habits and Life-history.*—The eggs are laid upon the bark of dead orange branches, and probably also on Hickory and other close-textured woods. The branches attacked are invariably dead and quite dry, but still retaining their bark. The larva never penetrates the living parts of the tree, and will perish of hunger if the supply of dead wood and bark is not sufficient for its support. The larvæ of different ages are found during the latter part of summer. Some of them change to pupæ in the fall, while others, after excavating their pupa cells, occupy them during the winter as larvæ, and undergo their transformations in the spring. Of those which pupate in the fall, some become perfect insects before cold weather, and beetles will be found in the cells as early as January; they do not, however, leave their retreats until summer weather has begun. The beetles continues to appear as late as May and June.

As a scavenger, assisting in the return to earth and air of the dead and useless material that has been assimilated by the plant, this can only be considered a useful insect, and certainly one that is incapable of doing any injury to the orange tree, either by causing disease or by direct loss of wood or bark.

### THE CYLINDRICAL BARK-BORER.

(*Hypothenemus eruditus* Westwood.)

[Plate XIV, Fig. 1.]

This minute beetle is frequently an object of suspicion from its presence in great numbers in twigs killed by dieback. It is 1.6$^{mm}$ ($\frac{1}{16}$ inch) in length, dark brown in color, cylindrical, and obtusely rounded at both ends. Under a lens it has a hoary appearance, owing to the short, stout hairs with which all parts of the body are clothed. On the wing-cases these stout hairs are arranged in numerous longitudinal rows, and the interspaces between the rows of hairs are deeply and coarsely pitted or punctate. The head is directed downwards and is not seen from above. The declivity of the thorax above the base of the head is covered with minute tooth like asperities.

The larva as well as the beetle itself feeds upon dry corky wood and bark of various trees, and upon plants having soft or porous tissues, such as are found in the Grape and many other vines. They riddle the dead wood and bark with galleries, and quite rapidly reduce it to powder.

In the Orange their galleries are seldom found in solid wood, but invariably occur in the bark and in small twigs when from any cause they have been deprived of life and become dry. Succulent shoots killed by frost or disease attract the beetles in great numbers as soon as they become dry and brittle; but no part of the tree is attacked as long as it retains its sap or remains moist. The insect is therefore entirely harmless in its operations, and beneficial rather than injurious to vegetation.

*Life-history.*—The larva of Hypothenemus is a minute white grub, with a thick and stout cylindrical body, strongly curved, and without legs or other organs of locomotion, save that by the contractile movements of its body joints, it is enabled to crawl slowly through its burrows. The head is small, and all the parts surrounding the mouth, with the exception of the pair of stout jaws, are so minute that they can be discerned only after careful dissection upon the stage of a microscope.

The family *Scolytidæ*, to which this beetle belongs, number in the United States at least two hundred species,* divided among numerous genera. All of them have wood boring habits, and members of the same group resemble each other closely. The larvæ of the different species are for the most part indistinguishable; the points of difference, if any exist, are so minute that they have escaped observation.

The pupa is formed in a little cell, walled off from the galleries made by the larva. It shows the form of the beetle, and is white, turning brown as it approaches maturity.

The eggs are white, oval in shape, and are scattered by the mother either singly or in little groups at random in the galleries which she excavates.

*About one hundred and seventy species have been described.

*Broods.*—There does not appear to be any definite number of broods. The beetles are rather more abundant in spring and early summer, and the larvæ in midsummer and winter; but the insect propagates at all seasons, and its development is only interrupted by frosty weather.*

### OTHER BEETLES BORING IN ORANGE WOOD.

In addition to the species hitherto mentioned, which are so frequently found in the wood of the Orange that may properly be considered a part of the regular fauna of the tree, there are numbers of other wood-eating Coleoptera, which are less obviously connected with the plant, but occasionally feed upon it, and have been bred from the dead limbs and twigs. A few species demand notice.

Two of these, *Leptostylus biustus* Lec., and *Hyperplatys maculatus* Hald., are closely allied Longicorn beetles, and belong to a group of that family, all the species of which are wood-scavengers, feeding only upon dead portions of plants.

*Leptostylus biustus* Lec. (Plate XIV, Fig. 2) is an ash-gray insect, with a rather broad and flattened body, the upper surface of which is broken by minute elevated points. The terminal third of the wing-cases is darker in color, and this darker portion is separated from the remainder by sharply defined lines meeting in a point upon the center line. Length, 7.6$^{mm}$ ($\frac{3}{10}$ inch). The antennæ are one-third longer than the body.

The larvæ are cylindrical, slightly flattened sawyers, having the first joint of the body somewhat enlarged; the head is very small, and almost concealed within the enlarged first joint; color pallid, except the jaws, which are chitinous brown.

The larva tunnels dead branches the wood of which is not too hard, or excavates galleries under dead bark of the Orange, filling up the passage behind it with tightly packed sawdust. It transforms to the perfect beetle at the end of its gallery, in a cell-like cavity formed by the movements of the larva in the surrounding mass of loose woody fragments.

The beetles appear in April and May, and there is a supplementary brood in September, although the perfect insects frequently remain in their cells all winter.

*Hyperplatys maculatus* Hald. (Plate XIV, Fig. 3) is a somewhat smaller beetle than the preceding, and its form is more slender and flattened. The color of the body is ash-gray, spotted above with dots of velvet black, and with a large splash of the same on each wing-case near the tip; the legs are black, variegated with red; the antennæ are much longer than the body, and are also variegated red and black. Length, 6$^{mm}$ ($\frac{24}{100}$ inch).

In its habits this beetle does not differ from *Leptostylus biustus*, and the larvæ of the two species resemble each other closely.

* Further notes concerning the habits of this beetle will be found in an article by Mr. E. A. Schwarz, in the Bulletin of the Brooklyn Ent. Soc., vol. VII, page 84.

*Amaurorhinus nitens* Horn.—This is a small, elongate beetle, shining black in color, and provided with a short beak or snout.

It is not uncommonly found boring in winter-killed twigs of Orange, or in portions of wood and bark which have been softened and rendered porous by the action of a wood-destroying fungus. The larva and other immature stages have never been observed.

The family of the *Cossonidæ*, to which this beetle belongs, comprises small insects, all of which, as far as their habits are known, feed upon dead bark, pith, or spongy wood, and fungus. The above species is as harmless as others of its family. It enters and feeds upon the wood after all life has left it, and is probably attracted by the presence of a fungus to the diseased portions which it infests.

### *INSECTS FOUND IN WOUNDS AND FOOT-ROT SORES.*

Bleeding wounds, especially sores in which fermentation of the sap is taking place, are very attractive to insects of many kinds. It therefore frequently happens that some harmless sap-feeding insect is mistaken, by those who are ignorant of its habits, for the originator of the mischief.

A list of insects which through misapprehensions of this sort have been reported by orange-growers as causing foot-rot, includes (1) *Sap-feeders;* beetles of the families *Nitidulidæ* and *Monotomidæ*, which live in all stages upon the fermenting sap of plants. (2) *Euphoria sepulchralis* (Fab.), a Lamellicorn beetle, which is not unfrequently found sipping the sap; and the white, thread-like maggots of small flies, which almost invariably make their appearance in sour sap. (3) *Midas clavatus* Drury (Plate XIV, Fig. 4), a large black fly, with an orange-colored band on the abdomen, which hovers about the diseased spots in order to prey upon flies and other insects attracted to the flowing sap. (4) Scavengers, feeding upon the dead wood and bark; these include besides the Termites, of which mention has been made in a previous chapter, several sawyers or larvæ of beetles belonging to the Longicorn family, but of unknown species. (5) A number of minute beetles, *Læmophlæus*, *Lathridius*, *Sacium*, *Hesperobænus*, and others, commonly found under the dead bark of trees, after it has been loosened by the gnawing of wood-eating insects. They are for the most part predatory upon the other insect inhabitants of these lurking places, and their larvæ may be found pursuing and devouring the young of the wood-scavengers, or even making war upon each other.

### *INSECTS FEEDING UPON DECAYING FRUIT.*

#### SAP-BEETLES. (Family *Nitidulidæ*.)

Two species of this sap-loving family are so constantly found in rotting oranges, and also in injured fruit, before it has fallen from the tree, as sometimes to occasion the suspicion that they are responsible for the splitting of the rind at the time when the orange is maturing. It has,

however, been ascertained that these beetles only attack the orange when the rind has been ruptured by accident or disease, or when it is softened by decay.

*Carpophilus mutilatus* (Fab.; Plate XIV, Fig. 5) is dull red-brown, with the disk of the wing-covers lighter; the latter do not reach the end of the body, and leave the last two joints exposed to view. The length of the adult is 2.8$^{mm}$ ($\frac{11}{100}$ inch).

The larva has a rather long, cylindrical body divided into simple rings or joints; the color is dull white, with the head and first joint of the body brown; the last joint terminates in a pair of notched spines or conical projecti ons toothed at the base.

*Epuræa æstiva* (Linn.; Plate XIV, Fig. 6) is shining, uniformly yellowish brown; the wing-covers nearly cover the body, leaving only the tip of the last joint exposed. The insect is smaller than the preceding; length, 2.2$^{mm}$ ($\frac{8}{100}$ inch).

The habits of these two beetles are very similar and they are always found together, although the Epuræa is usually present in greater numbers than the Carpophilus.

In September they appear in great numbers in every grove where rotting fruit is allowed to remain upon the ground. The active larvæ, as well as the perfect insects, soon swarm in the rotting fruit, and being active in flight, the beetles seek out and penetrate the split or injured fruit even upon the trees.

They can, however, scarcely be considered injurious insects, as they are not capable of penetrating the fruit of their own accord, but merely take advantage of any chance opening to gain admittance to the pulp. The effect of their attack is simply to hasten by some hours the decay which inevitably follows any external injury to the rind.

The pupæ are formed in the earth; those of Epuræa just beneath the surface, and those of Carpophilus at a depth of several inches. They occupy small oval cavities made by the movements of the larva.

Development in these beetles is very rapid; the interval between broods does not exceed twenty-five days. Of this period, about ten days is passed as larva and eight or nine days as pupa; the remaining six or seven days are occupied by the beetles in coupling and ovipositing, and by the hatching of the eggs.

### WINE OR POMACE FLY OF THE ORANGE.

Associated with the two beetles mentioned above is a little pale yellow fly of a kind that is familiar to most housekeepers under the name of "wine fly" or "vinegar fly." It has a rosy-red head and brick-red eyes; the joints of the abdomen are bordered above with black. Length of the fly, 2.6$^{mm}$ ($\frac{1}{10}$ inch).

The maggots of this fly are found in great numbers in company with the larvæ of the sap-beetles in rotting oranges, through the pulp of

which they burrow in every direction and greatly increase the rapidity of decay.

The maggot is transparent white, with a cylindrical body, thickest at the posterior end, and tapering to a sharp point at the head; the body joints are very prominently ringed. At the posterior end a pair of projections form the principal breathing organs. The head ends in a pair of hooked jaws, which have the raking movement common to most fly larvæ. The dark color of the jaws and frame-work which constitutes their base renders them visible through the transparent walls of the body.

In pupating, the larva enters the earth a short distance, or remains attached to the under side of the orange as it lies upon the ground. The larva contracts and its skin hardens, forming a casket-shaped puparium, about one-third as wide as long. The puparium is chestnut-brown in color; it retains the breathing-tubes of the larva, but is distended and slightly altered in form by the hardening of all the parts.

The wine-fly undergoes all its transformations within two weeks. This rapidity of development is evidently necessary, as the insect is dependent upon the juices of the orange, not only for its subsistence in the larva state, but also for the moisture necessary to sustain life in the pupa.

### OTHER SPECIES.

The two beetles and the wine-fly above mentioned sometimes become annoying pests in the packing-house when piles of decaying fruit are allowed to remain about the premises, but are easily banished by clearing away the refuse, and maintaining cleanliness. In the grove, if the dropped oranges are picked up regularly, and the ground about the trees kept clean, these insects will rarely make their appearance. If, through carelessness in this regard, they are allowed to become numerous and infest the grove, thorned and split fruit, which might otherwise be used for wine-making, will, owing to their attacks, be rendered useless for this and other purposes, even before it has fallen from the trees.

Other closely allied beetles and other species of flies are found to infest injured or rotting fruit. Two only can be mentioned at present; they are—

(1.) *Smicrips hypocoproides* Reiter, a minute Nitidulid introduced from the West Indies, but which has become quite abundant in parts of the southern United States, and is found feeding upon sap and also in rotting cotton bolls.

(2.) *Europs pallipennis* Lec., a rare Monotomid beetle.

*Fruit-eating Ant.*—A small dark-brown ant, a probably undescribed species of Lasius, is sometimes found gnawing the pulp of split oranges upon the tree. A stream of the ants may be seen carrying bits of the fruit down the trunk of the tree.

*INSECTS IN DRY FRUIT.*

BLASTOBASIS CITRICOLELLA Chambers.

This small moth, belonging to the family Tineidæ, is described in the Report of the Commissioner of Agriculture for 1879, p. 207, where the following note concerning it occurs:

"From a dry orange which was found at Jacksonville, Fla., in the latter part of January, and preserved on account of its being infested by a small beetle (*Arœocerus fasciculatus*), there issued rather unexpectedly on March 17 a small gray Tineid moth, which was referred to Mr. Chambers for determination. * * *" The full description is given on the same page.

ORANGE-EATING TINEID.[15]

Another minute moth of the same family as the preceding (*Tineidæ*) was bred from the pupa found in a crevice of the rind of a split orange. The pupa was enveloped loosely with silk, in which were entangled the droppings of the larva, and was otherwise surrounded with evidences that the insect had fed upon the dry portions of the rind. The moth issued early in October and proved a very handsome insect of dark color, with scales of lustrous lead-color on the upper wings and body, the surface having a violet sheen. The head and thorax are iridescent dove-color. On the margin of the upper wing, at its base, is a membranous flap (costal fold), which can be folded beneath the wing or opened widely, disclosing a lining of delicate hairs, arranged in three tufts, the lower one forming, when erect, a rosette of lemon-yellow color; above this a tuft of orange yellow, and the upper tuft a pencil of purple hairs.

ARÆOCERUS FASCICULATUS (De G.).

This little brownish beetle is commonly found in dry or blasted bolls of cotton. It is also said to be injurious to coffee in Brazil. In the Report of the Commissioner of Agriculture for 1879, p. 206, mention is made of its occurrence in a dry orange. The larva and pupa, as well as the perfect insect, were obtained at the same time.

WHITE ANTS (TERMITES) IN FRUIT.

The fruit of the Citron, when growing upon recumbent branches and when touching the earth, is frequently entered by Termites and entirely destroyed by them. Oranges which have fallen from the trees and are allowed to remain upon the ground are also attacked, but less frequently than the citron. The Termites feed upon the thick inner rind of the citron, and upon the membranous divisions in the orange. They

enter the fruit from beneath, through a small perforation made in the rind. The Termites never ascend the trees or attack fruit which is not resting upon moist earth. Their appetite for this sort of food is not very strong, and the loss they inflict cannot be considered serious. If citrons are attacked the fruit should be raised from the ground or allowed to rest upon a dry support, and the ground around and under the bushes should be frequently stirred with a rake.

# CHAPTER XII.

## PREDATORY INSECTS.

### INSECTS PREYING UPON APHIS.

*LADY-BIRDS.—COCCINELLIDÆ.*

Several species of this family have already been noticed as predatory upon Scale-insects; nearly all the species, and they are very numerous, prey to a greater or less extent upon Aphis. Of the larger forms, which are familiar everywhere under the name of Lady-birds, four species are commonly found feeding upon the Orange Aphis in our groves. They are *Chilocorus bivulnerus* (Muls.);* *Exochomus contristatus* (Muls.);† *Cycloneda sanguinea* (Linn.);‡ and *Hippodamia convergens* Guér.§ These have all been mentioned as preying upon scale-insects. Among the smaller members of this family are numerous species of the genus Scymnus, which prey upon Plant-lice, and most of them are found from time to time upon the orange trees. The form in Scymnus is rounded and very convex; the color in most of the species is a somber brown, sometimes relieved with blotches of dull red or yellow. The body is always hairy. In size the species range from one-tenth to one-twentieth of an inch in length. They are apt to resemble each other closely, and in some groups the species are distinguishable the one from the other only on the closest analysis.

The larva of Scymnus is rather thick and short, the body dark-brown, purple, or black, but entirely covered above with tufts of white wax, which are easily rubbed off in handling the insect.

The pupa is found within the split skin of the larva, as with the larger species of Lady-birds.

#### SCYMNUS CAUDALIS Lec.

In this species the body is black, with the head and parts of the thorax red; the end of the body and the legs yellowish-red. Length, $2^{mm}$ ($\frac{8}{100}$ inch).

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* Black, with two red spots.

† Smaller in size. Red, with two black spots.

‡ Blood-red or brick-red, without spots.

§ Orange-red, with five or six spots on each wing-cover.

This is the commonest and one of the largest species found among Plant-lice on the Orange in Florida. Certain other species, almost equally common, are entirely black, and differ the one from the other only in size, and in characters too minute for popular description.

The larvæ of all the species bear white flocculent tufts, and have no marks by which the species can be readily distinguished. They are quite active when disturbed, but are usually seen quiescent in the midst of the unresisting herd of Aphis, feeding upon the young lice.

They undergo their transformations upon the leaves among the remains of the Aphis colonies destroyed by them and other enemies. The pupa is held in the split skin of the larva, and is dark-colored like the body of the latter.

### *SYRPHUS FLIES.—SYRPHIDÆ.*

Whenever colonies of Aphis are found on the Orange there will almost invariably be found among them slug-like larvæ, which creep about among the Plant-lice with a leech-like movement, now contracting into an almost globular mass, and again elongating like the joints of a telescope. The minute terminal joint, which constitutes the head of the larva, is observed to possess a pair of retractile horny hooks, which work forwards and back, in and out of the mouth, like a rake. As the larva advances with a groping motion, for it is quite blind and eyeless, the outstretched neck and head sweep the surface, and the jaws continue their raking movement until they strike the body of an Aphis. Immediately the jaw-hooks grapple their unresisting victim, and soon through the transparent walls of the body the sucking stomach is seen pulsating and drawing through the œsophagus in a continuous stream the green juices of the plant-louse.

When actively engaged in feeding these larvæ continue with the greatest voracity to empty one louse after another, until they have destroyed dozens of them; and their bodies, distended with the contained juices, become translucent green in color. When filled to repletion, the larva falls into a lethargy, lasting two or three hours; during which the processes of digestion change the juices of the body to varying shades of brown, and dark masses of fecal matter gradually form in the intestines. The curious changes of color in the semi-transparent larvæ are therefore due entirely to the condition of the body-contents. Full fed individuals usually have a tinge of flesh color, owing to the formation of glandular, creamy masses of fat, which have a roseate hue. When fasting through scarcity of food, the fat is absorbed and the body becomes dark-brown and opaque. While feeding the larva is translucent green; while digesting the colors change to olive and brown, with distinct markings of reddish brown and black.

*Transformations.*—When full fed the larva attaches itself by means

of a pair of terminal prop-legs, aided by a viscid secretion which it voids, and which in drying glues it to the surface of the plant. The body becomes distended and thickened, losing in length what it gains in girth. The skin of the larva is not split or shed, but hardens and forms the puparium, which protects the true pupa within. In the puparium the shape of the larva is profoundly altered, the body joints are obliterated, the anterior end becomes swollen and broadly rounded, and the form tapers suddenly behind.

The perfect fly issues by pushing off the convex end of the puparium, which splits at the suture between two of the old larval joints, and releases a circular cap, in the shape of a watch-glass.

The duration of the egg and larva periods in these Aphis-eating flies is short; the egg hatches in forty-eight hours after it is laid, and the larva becomes full grown and forms its pupa in five or six days. About ten days, the average time with insects having many broods, are passed in pupa. The reason of this extremely rapid development in the first two stages, the egg and larva, becomes obvious when we consider how brief is the existence of the Aphis itself, and how suddenly its colonies appear and disappear; for the life of a colony of Aphis is also very short. Upon the Orange the Aphis can feed only upon the very tender young leaves; in a short time these harden, and then the colony must scatter; but frequently, long before that time, their numbers are reduced almost to extermination by enemies and parasites. As the Syrphus larvæ cannot follow the winged insects, they must make the best of their limited opportunities and feed quickly or perish of starvation. It is curious to mark how nature in the case of these insects has responded to the necessities of the situation and given their larvæ restless activity, great rapacity, and destructive powers, notwithstanding their slow locomotion, and also a remarkably brief egg period, so that this wingless, blind, and almost legless maggot is enabled to compete with more perfectly organized rivals in the food struggle which takes place over every Aphis colony.

*Broods, &c.*—The larvæ of these Syrphus flies feed only upon Aphis and depend upon them for their existence. They therefore appear and disappear with the colonies of the latter, and the broods may be supposed to follow rapidly one upon another during the seasons of growth, when the appearance of new shoots upon the Orange gives support to numerous colonies of Aphis.

The seasons of growth in the Orange, after the renewal of the foliage in the early spring, depend in a great measure upon the prevalence of rains and vary from year to year, but are usually three or four in number during the year. The colonies of Aphis and likewise their Syrphus enemies are most abundant in June and September.

Three representatives of the family Syrphidæ are found among Aphis on the Orange. They belong to the genus Baccha.

## THE FOUR-SPOTTED APHIS-FLY.*

(*Baccha babista* Walker.)

[Figs. 81, 82 and 83.]

This is a rather slender fly, with a large, well-rounded head, and a club-shaped hind-body, supported on a slender stalk or peduncle; the eyes, which cover the greater part of the head, are mahogany-brown; the thorax black, with a metallic luster, and with a golden-yellow shield; the wings are transparent; the club of the abdomen brown, marked with four pale triangular spots. (Fig. 81.) Length, 10$^{mm}$ ($\frac{4}{10}$ inch).

FIG. 82.—*Baccha babista*, larva. (Original.)

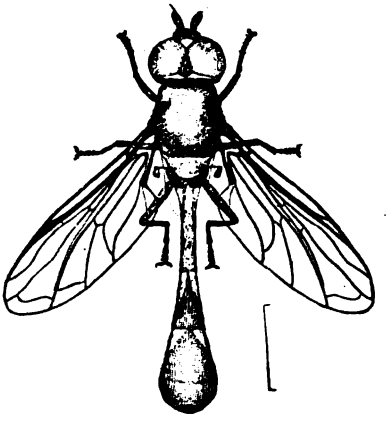

FIG. 81.—*Baccha babista*, adult. (Original.)

The larva (Fig. 82) has a cylindrical body, greenish, with a longitudinal band of dull red on the back; the joints about equal in size, except the first three, which are tapered, and form a retractile neck; the surface is covered with very short, stiff hairs, giving it a velvety appearance; each joint of the body is armed with a row of soft spines above and a pair of fleshy prop-legs below. Length, when at rest, 7.5$^{mm}$ ($\frac{3}{10}$ inch).

*a.*

*b.*

FIG. 83.—*Baccha babista*, puparium: *a*, dorsal view; *b*, lateral view. (Original.)

The puparium, or chrysalis (Fig. 83), has the form of a cone, with one side flattened and fastened to the surface of the leaf; the large end is broadly rounded, convex; the color varies from dirty white to dull yellow, and there are more or less distinct cross-shaped markings upon the back; the spines of the larva shrink to minute prickles on the puparium.

The eggs are elongate-oval, brilliant white, the surface marked with diamonds by obliquely intersecting engraved lines. They are deposited by the parent fly singly upon the leaves among Plant-lice.

*Parasites.*—Minute Chalcid parasites prey upon the Syrphus larva,

* This very common species has been described by Mr. Ashmead under the name *Conops? quadrimaculata*. (Orange Insects, page 69.)

and issue from the puparium, in numbers varying from six to eighteen, through a number of small holes which they gnaw in its top and sides. They are from 1mm to 2mm in length, and have the dark bronze and metallic colors with hyaline and iridescent wings so common in this family (*Chalcididæ*).

### THE DUSKY-WINGED APHIS-FLY.

(*Baccha lugens* Loew.)

[Fig. 84.]

Another species of Baccha, scarcely less common than the preceding, has a more leech-like larva, in form flattened and dilated behind, but with the anterior joints lengthened into a very mobile and extensile neck. The surface of this larva is nearly smooth, without the spines or velvet hairs of the first species. In color the larva is dark, inclining to purple when not feeding, with cream-colored blotches, tinged with pink. The length in repose is about 8mm ($\frac{32}{100}$ inch).

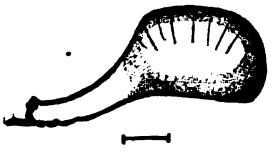

FIG. 84 — *Baccha lugens*, puparium. (Original.)

The puparium (Fig. 84) is dull brown, gourd-shaped; the anterior portion greatly inflated and behind suddenly flattened and contracted to form a sort of handle. The terminal spiracles of the larva are seen at the tip of the handle-like abdomen, where they form a pair of wart-like prominences.

The fly does not differ greatly in form from the preceding; it has eyes of brighter red, and the wings are distinctly clouded with spots of brown; the thorax less shining, dark bronze; the shield (metathorax) dark bronze, like the thorax; abdomen thicker, less broadly dilated at the end, uniform brown in color. The size of the imago varies greatly, from 8mm ($\frac{32}{100}$ inch) (small males) to 12mm ($\frac{48}{100}$ inch) (large females).

The egg is indistinguishable from that of *Baccha babista*.

### THE RUDDY APHIS-FLY.

(*Baccha cognata* Loew).

A third species of this genus is found in company with the preceding species preying upon Aphis, sometimes upon Orange, but more frequently upon different kinds of Plant-lice found on herbaceous plants and weeds of the garden. In this species the form of the fly and its larva approach closely to that of *B. lugens*, but they are somewhat more slender and smaller than either of the preceding species. In the perfect fly the color of the eyes is mahogany-brown; the thorax black, not shining; the wings densely clouded with red-brown; the abdomen dull red, and very slightly dilated at the tip.

*Larva.*—The maggot has the form and smooth surface of *B. lugens*, but is more transparent and lighter in color, yellowish-green and white predominating.

### THE PRUINOSE APHIS-FLY.*

[Figs. 85 and 86.]

A very common enemy of the Orange Aphis is a small two-winged fly. Its young is a greenish, slug-like maggot, 3$^{mm}$ ($\frac{12}{100}$ inch) in length; the body is flattened beneath, convex above, with two deep longitudinal furrows on the back; the joints of the head and neck are small and tapering, as in the larva of Syrphus, and can be greatly extended or entirely withdrawn into the body; the body behind is rather broadly rounded; from the upper surface near the hind margin arises a pair of diverging appendages like the horns of a snail; the ends of these appendages are open pores, and the apparatus constitutes the principal spiracles, through which the animal breathes; the surface of the larva is roughened with minute knob-like excrescences.

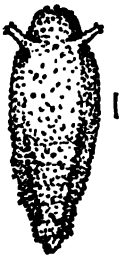

FIG. 85.—The Pruinose Aphis-fly, larva. (Original)

When ready to transform into pupa, the larva glues itself to the surface of the leaf by means of a black gum. The body of the larva shortens and thickens, becomes oval in shape, and assumes a golden-brown color, the breathing tubes are now very prominent, the lateral furrows of the larva are not obliterated, but divide the puparium into longitudinal lobes, and appear as broad bands of darker color upon the surface of the casket.

When vacated by the fly the puparium splits in a ring near the anterior end, releasing the tip in the form of a conical cap the cap also splits across the middle, dividing into two valve-like halves, only one of which is usually thrown off by the fly in its exit.

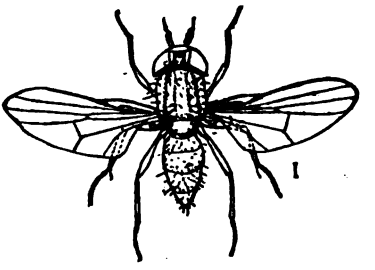

FIG. 86.—The Pruinose Aphis-fly. (Original.)

The fly (Fig. 86) is a small, thick bodied insect, about 2$^{mm}$ ($\frac{8}{100}$ inch) in length, with deep purple eyes, transparent wings, and particolored legs; the body is bluish-white (pruinose), with sparsely placed black hairs; the upper surface of the thorax is marked with four longitudinal stripes of umber-brown. The egg is white, elongate oval, with fine longitudinal lines; it is fastened to the surface of the leaf among the living Aphis.

*Transformations.*—What has been said of the habits and transforma-

* Dr. S. W. Williston writes concerning this species: "They are evidently Anthomyids, but I cannot place them in any of the European genera. I am acquainted with a number of the Anthomyid genera, but this species differs from any I know in the few bristles on the head and face."

tions of the Aphis-eating Syrphus-flies will apply equally to this insect, and it is found in company with them not alone upon the Orange, but among various species of Aphis on other plants as well.

*Parasite.*—A minute Hymenopterous fly (a Pteromalid)[16] attacks the larva and issues from the puparium through round holes eaten in its side. Two specimens of the parasites were bred from a single puparium of the fly. They issue in September.

## OTHER PREDATORY INSECTS FREQUENTING THE ORANGE.

### *PREDATORY WASPS.*

### POLISTES AMERICANUS (Fabr.).

[Figs. 87 and 88.]

This large red wasp is fond of making its home under the dense foliage of the orange tree, and suspends its comb of paper to the branches.

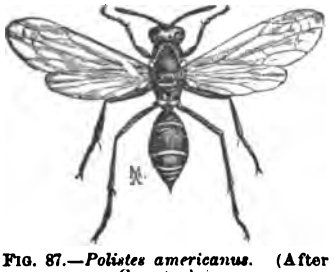

FIG. 87.—*Polistes americanus.* (After Comstock.)

It is a large species, and its sting is equal in severity to that of the white-faced hornet. Fortunately, it is not an irritable wasp, and is little inclined to use its weapon, except when its nest is attacked.

Like most insects of its kind this wasp is carnivorous, and to a great extent preys upon caterpillars and soft-bodied insects. With these it feeds its young, first masticating the food into a pulpy ball, in order that it may readily be swallowed by its young, which are not provided with horny jaws, and then presenting it to the latter in their cells in much the same fashion that a bird feeds its nestlings. Not only the grubs are fed in this way, but also the young wasps which have recently issued from the pupa, and which do not for some time leave the nest or take part in the labors of the colony.

FIG. 88.—*Polistes* nest in spring. (After Riley.)

The nest consists of a single comb or layer of cells, which is increased in size by the addition of new cells around the edges until it sometimes attains the diameter of 10 or 12 inches. The comb is not protected by a covering of paper, as in the nest of a hornet, but the cells are built with the mouth downwards, and the back of the comb is made very thick and strong, so that it sheds water.

The wasps make their comb of wood masticated to a pulp. They may be seen gathering for this purpose from fence rails and unpainted wood surfaces the fibers beaten out by the action of the weather. The leaf-rolling caterpillars which injure the buds and tender shoots of the Orange form a very considerable portion of the food of all colonies of Pol-

istes which have established themselves in the vicinity of orange groves. Numerous other insects are also destroyed by them. The orange-grower should not, therefore, be concerned to find them building their nests in his orange trees, and it is greatly to his interest to allow them to remain. The ordinary operations of cultivating and pruning rarely disturb these insects, who pay no attention to the methodical movements of the horticulturist, and only resent a direct attack. Before the time for gathering the oranges the nests are usually deserted by the wasps and the colonies dispersed, for they do not continue to breed during the winter months even in Florida.

### THE VASE-MAKER WASP.

(*Eumenes fraterna* Say)

[Fig. 89.]

This is also a useful predatory wasp, and is never known to use its sting unless caught and held in the hand. It is $\frac{8}{10}$ inch in length; the color is black with white markings. The abdomen is borne on a slender stalk or peduncle, and forms a rounded knob, prolonged at the extremity in a rather blunt point. Each side of the swollen portion of the abdomen is marked with a white spot.

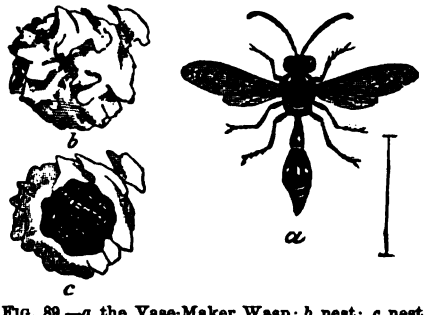


FIG. 89.—*a*, the Vase-Maker Wasp; *b*, nest; *c*, nest showing interior stored with caterpillars. (After Riley.)

The female of this wasp is solitary and makes single cells of mud and sand, which she attaches to various plants, and not infrequently to the twigs of orange trees. These mud cells are almost spherical, about three-fourths inch in diameter; the walls are thin and fragile; they have an opening which is provided with a projecting lip or ring and the structure resembles a globe-shaped flask, with a very short neck. Within the cell the female deposits a single white egg. She then packs it with small caterpillars, each of which is paralyzed and rendered helpless by a stab from her sting, and seals the opening with soft mud.

Each female constructs a number of cells, but scatters them about, seldom placing more than one or two in the same place. When filled and sealed up they are abandoned. The grub of the wasp feeds upon the caterpillars stored for its use; when all are consumed it forms its pupa within the cell, and in due course of time issues as a perfect insect, removing with its jaws the earthen stopper of its doorway.

*Broods.*—There are broods in spring and fall. The summer months are passed as pupæ, and the winter as perfect insects.

*Parasites.*—This wasp, in common with many other cell-making Hymenoptera, has an enemy which destroys the grub and occupies its place within the cell, issuing in its stead through a round hole made in its side. This parasite is a brassy-green Cuckoo-bee belonging to the genus Chrysis. It is remarkable for its bright metallic green or blue color, hard texture, and coarsely pitted surface, and the peculiar form of the abdomen, which is abruptly truncate behind and hollowed from the under side and is capable of folding over upon the head and breast, protecting the members in its hollow under surface, and making of the insect almost a compact ball. This position the insect is apt to assume when captured or disturbed. The perfect insect is $11^{mm}$ in length ($\frac{44}{100}$ inch) when fully extended.[17]

Other parasitic Hymenoptera have been bred from the cells of this wasp, but some of them (*Braconidæ*) are parasitic upon the caterpillars stored as food by the wasp, and not upon the young of the wasp itself. The eggs of these parasites existed in the bodies of the caterpillars before they were captured and placed in the cells by the mother wasp, and it is noteworthy that such parasitized caterpillars are not eaten by the wasp-grub; probably because they are soon destroyed by their internal enemy, and their bodies rapidly become too hard and tough for the weak jaws of the wasp-grub. It is also to be remarked that the poisoned sting of the wasp while paralyzing the caterpillar, does no injury to its internal parasite, but the latter completes its transformations as well shut up within the tightly sealed cell of the wasp as under normal conditions in the open air. The parasite fly, having cut its way out of the hardened skin of the caterpillar, finds itself still inclosed within the wasp cell, the walls of which it is unable to penetrate, and it therefore remains imprisoned until released by the exit of the wasp, for the presence of the caterpillar parasite in its cell in no way interferes with the transformations of the latter.

### *THE CAMEL-CRICKETS OR SOOTHSAYERS.*

These are large insects, with attenuated bodies and long, slender legs, the first pair of which are elbowed and provided with sharp spines and hooks for capturing and holding their prey. The latter consists of insects of any sort, not protected by too hard a shell or other covering, but chiefly of flies and soft-bodied active larvæ. The camel-crickets do not molest Bark-lice, or other sedentary insects, and do not prowl about or spy into hidden places in search of food, but lie in wait for their prey, taking only that which comes within their reach; or they creep cautiously and slowly upon any small moving object which their keen and watchful eyes discover in their vicinity. When within reach of their prey, they seize it with the rapidity of lightning, and hold the struggling victim firmly clasped between the spines and grappling hooks of their fore legs.

Their manner of feeding is very unlike that of other insects, and reminds one of a monkey eating fruit; they appear to masticate their food very deliberately before swallowing, biting off a piece from time to time, while they hold it in their claws.

The head swings upon a very mobile neck, and can be turned so far to the side as to look almost directly backwards over the shoulders. Their quick movements betray an alertness, in striking contrast with the feigned sluggishness of habit. This evidence of watchfulness, while the insect, with fore-arms folded, and claws clasped in the attitude of prayer, remains motionless and apparently absorbed in meditation, gives an irresistably comic air of hypocrisy to its actions. These peculiar habits were well known to the ancients, for the group is represented by numerous species in many parts of the world, and they early received the name Mantis (prophet, or soothsayer).

### MANTIS CAROLINA.

[Figs. 90 and 91.]

This, the largest of our species, is not very abundant in Florida, but is sometimes seen upon orange trees, catching every moving insect that comes within the reach of its claws. It is yellowish green in color, and

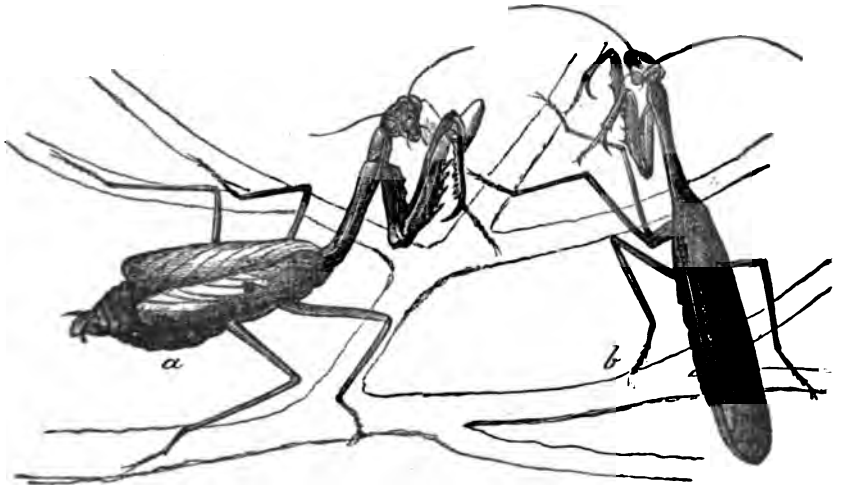


FIG. 90.—*Mantis carolina*: *a*, female; *b*, male. (After Riley.)

about two inches in length. It has wings in the adult state, which somewhat resemble folded leaves; each fore-wing bears a brown spot; in some exotic species the center of this spot is transparent, and resembles a hole eaten in the leaf by some insect. There is but one brood each year. The young hatch in early summer and complete their growth in the latter part of the season. The large egg-masses are glued to the

twigs of trees; they are elongate, irregularly oval, about an inch in length, and contain forty or fifty eggs. The eggs (Fig. 91) occupy flattened cells placed in two ranks, alternating with each other; the cluster of cells has a braided or woven appearance, but consists simply of a continuous ribbon of mucus folded in close flutings, and having an egg deposited in the bight or angle of each fold. The eggs are deposited simultaneously with the deposition of this ribbon by the mother insect, and the whole mass is at first soft and flexible, but rapidly hardens by exposure to the air.

FIG. 91. — Eggs of *Mantis carolina*. (After Riley.)

MANTIS MISSOURIENSIS?

In this species the body, though over two inches long, is but little thicker than a darning needle; the legs are very long and so slender that they seem hardly competent to sustain the weight of even so meager a body. The extreme attenuation of all its parts, and the light brown color of the insect, afford it protection from enemies, and enable it to advance unnoticed upon its prey. Its ghost-like form is difficult to detect upon plants, and it has the appearance of a straw caught in spiders' webs, an illusion which the insect with apparent design strengthens by frequently giving to its body a swaying motion as if vibrated by air currents.

This species is very common, and is frequently seen upon the Orange as well as upon other plants. It has a spring and fall brood. The egg-masses are brick-red in color, about half an inch long, and flattened upon the sides. They are usually deposited between the folds of a dry leaf or in crevices of the bark. The structure is the same as in the preceding species, but the cells are more distinct and regularly placed. The food of this Mantis consists chiefly of small flies, and neither this nor the preceding species are of much importance to the cultivator of plants, since they do not at all discriminate between his friends and foes, and do not seek out or destroy the more insidious enemies which lurk in hiding places, or those which protect themselves with a covering or scale.

*SOLDIER-BUGS.*

Among the true bugs (*Hemiptera*) are numerous predatory species, of which not a few frequent the orange trees. It is not easy to distinguish the predatory from the plant-sucking kinds, and, indeed, in some instances, the same bug has both habits. The most noteworthy instance of this is in the case of *Raphigaster hilaris*, already noticed in Chapter IX. This species, on occasion a very destructive pest of the plant, is at other times a useful insect, killing and sucking the juices of

plant enemies, particularly the leaf-eating caterpillars. Others of the Soldier-bugs feed upon the juices of the plant for a short time after hatching, and afterwards live exclusively upon insects.

The most rapacious of the bugs belong to the family Reduviidæ, and have the head well separated from the body by a more or less slender neck; they possess a stout, curved beak and long legs, well fitted for rapid movements. Many of these species bristle with spines, especially in the younger stages, and the usual colors are dark brown variegated with red.

### THE SPIDER-LEGGED SOLDIER-BUG.

(*Leptocorisa tipuloides* Latr.)

[Plate VI, Fig. 4.]

This species has already been discussed among the enemies of Bark-lice (see Chapter VI). It is very commonly seen upon the Orange, and frequents, often in great numbers, trees infested with Lecanium Scales, and not only sucks the juices of the Bark-lice, but also captures ants and other insects which are attracted by the lice.

This predaceous bug should not be confounded with the plant-sucking Red bug (*Dysdercus suturellus*), which does injury to the fruit. In Leptocorisa the form is slender; the body seven-tenths of an inch long and the legs longer than the body; the colors are orange and black.

The stouter form and deep-red color of the Red-bug render the two species distinguishable at a glance.

Leptocorisa must be classed among beneficial insects, since it feeds to some extent upon Plant-lice and Bark-lice; but, like many predatory bugs, it captures and destroys indiscriminately the friends as well as the foes of the plant. Possibly at times it subsists almost entirely upon the honey-dew ejected by Plant-lice. Acids as well as sweets appear to be suited to its taste, and it is one of the few insects known to prey upon ants, the juices of whose bodies are strongly flavored with formic acid.

The following soldier-bugs form part of a great army of predaceous insects which frequent the orange tree, but have no very close connection with the plant or its especial fauna.

### THE RAPACIOUS SOLDIER-BUG.

(*Sinea multispinosa*, De Geer.)

[Fig. 92.]

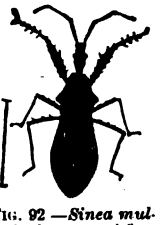

Fig. 92.—*Sinea multispinosa*. (After Glover)

Colors brownish, with a red stripe along the upper surface of the abdomen. The body is slender, but less so than Leptocorisa. The young bugs are said to feed upon Plant-lice; the adults, however, attack insects of large size.

### THE WHEEL-BUG.

(*Prionotus cristatus*, Linn.)

[Fig. 93.]

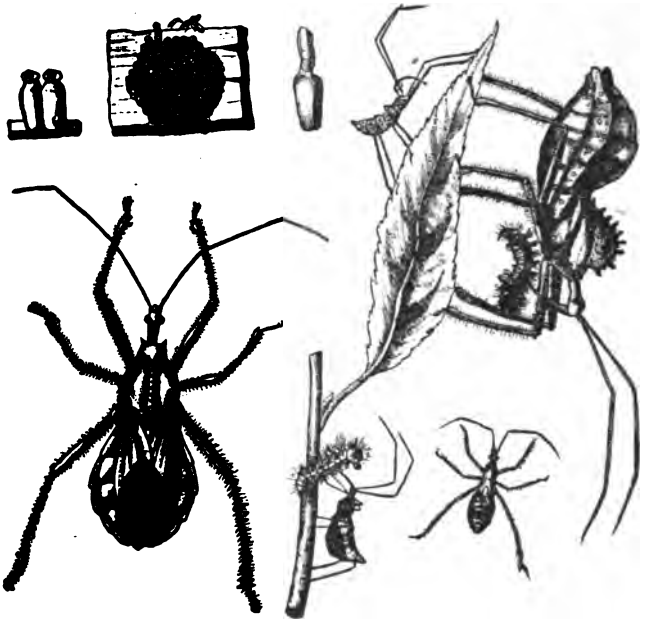

FIG. 93.—*Prionotus cristatus*. (After Glover.)

This large bug is not uncommon in orange groves. Its body and legs are covered with a coat of very fine, close down, giving it an ash-gray color; the thorax rises in a semi-circular ridge, which is provided with short, projecting spines, regularly placed, like the teeth of a cog-wheel; the head is small, but is armed with a powerful beak, which is capable of giving a poisonous stab, more painful to man than the sting of a hornet.

Mr. Glover, in the Report of the Commissioner of Agriculture for 1875, gives an extended account of this insect, and shows that it is very voracious in all its stages; the young prey upon Aphis and other small or soft-bodied insects, and after paralyzing them with their deadly sting suck and empty them of their juices.

The eggs are urn-shaped, as shown in the figure, and are deposited in large clusters, firmly cemented to each other, and placed in all sorts of situations, but usually upon some firm support, such as the trunk of a tree or the side of a building, or fence rail.

The young wheel-bugs are bright red with black markings.

The Green Soldier-bug (*Raphigaster hilaris* Fitch), the two species of Metapodius (*M. femoratus*, and *M. terminalis*), with the closely allied species, *Euthochtha galeator* Fabr., have already been noticed as partly plant-feeding, but with rapacious habits also.

## INNOXIOUS INSECTS.

### *CASE-BEARERS ON ORANGE.*

The trunks of orange trees are favorite feeding-grounds for the larvæ of several small moths of the family Tineidæ, which protect their bodies with cases formed of fragments of their food material. In the case of those species which are met with upon orange-tree trunks the food consists of lichens or other minute cryptogams found growing upon the bark.

A very common species belongs apparently to the genus Coleophora. Its case is dull white, about the size and somewhat the shape of a grain of oats; it is rather smooth outside, and seems to be formed of finely comminuted bark.

#### THE ORANGE CASE-BEARING TINEID.

(*Coleotechnites citriella* Chambers.)

This species was first made known in the Report of the Commissioner of Agriculture for 1879, which contains the following account of its habits. Mr. Chambers' descriptions of the genus and species will be found in the same report, page 206:

"At Manatee, Fla., in the latter part of April, I found upon the trunk of an orange tree the case of a Tineid larva. This case was rather slender, 11$^{mm}$ (.43 inch) long, and rather pointed at the hinder extremity. It was dark gray in color, resembling the bark upon which it was found, and was apparently composed of small bits of lichens and excremental pellets, with much gray silk. The moth issued March 6, and upon being referred to Mr. Chambers proved to be a new species representing a new genus."

### *BARK CLEANERS.*

Among the host of harmless insects that from time to time make their appearance upon the orange tree, there is a group of scavengers that frequent the trunks and assist in cleansing the bark, by devouring the fungi, molds, or excreta of other insects that befoul its surface. Of these the most conspicuous examples are certain nerve-veined insects (Neuroptera) belonging to the genus Psocus.

#### PSOCUS VENOSUS Burm.

The adult of this species is smoky-brown; head dark bronze; antennæ dusky, lighter at the base, densely hairy in the male; thorax margined with yellow; fore-wings almost black, the three basal veins yellow,

with a triangular spot of yellow color (pterostigma) near the margin toward the tip; hind-wings smoky, hyaline; feet yellowish, with dusky tips; length 5mm to 8mm ($\frac{3}{16}$ to $\frac{5}{16}$ inch).

These little animals are seen upon the trunks of orange trees in flocks numbering from a dozen to forty or fifty individuals. They feed in companies and browse upon the lichens which they cleanly remove from the bark, leaving a clear space behind them. The colonies consist of one or more families and include individuals of all ages, the wingless young herding with the adult insects.

The adults, although winged, do not readily take flight. When alarmed the troop huddles together for mutual protection like sheep, but if directly attacked, or when seized with a sudden panic, they scatter in every direction and run nimbly over the bark, with which their drab colors harmonize so closely that they are not easily distinguished upon its surface. If left undisturbed, the herd in a short time reassembles and quietly resumes its methodical attack upon the lichens.

The eggs are oval, glistening white; they are laid upon the bark in batches of 15 to 30, deposited on end in several rows obliquely overlapping each other, and the batch is protected by an oval, convex shield of comminuted wood which surrounds and adheres closely to the eggs.

The females watch their eggs, and as soon as they are hatched lead their young ones forth to pasture.

This delicately organized insect is fond of shade and moisture and is most commonly seen in densely-shaded groves and old gardens. It is not restricted to the orange, nor is it compelled to live upon plants alone; it may thrive on walls or fences, wherever lichens grow. The smooth bark of the orange, when conditions favor the growth of fungi, affords excellent pasturage to this Psocus and it frequently becomes very abundant.

It is hardly necessary to point out that to the extent of its feeble powers this is a useful insect, and its presence should excite no alarm. *Psocus venosus* is more distinctively a northern than a southern insect and does not inhabit the extreme southern portion of the orange district in Florida. The adult insects hibernate and begin breeding early in the spring.

### THE ORANGE PSOCUS.

(*Psocus citricola* Ashmead.)

This is a smaller species than the preceding. Length 2.5mm to 3mm ($\frac{10}{100}$ to $\frac{12}{100}$ inch). The color is white or pale yellow; the adults have very transparent, hyaline wings. At all ages the semi-transparent body shows the color of the intestinal contents, which varies considerably with the condition and nature of the food. This consists of the wax and other soft excretions of Bark-lice, of honey-dew, and probably

also of minute fungi or their spores, which germinate on leaves and bark infested with insects.

The eggs are pearly-white and are laid in hollows upon orange leaves, in clusters of ten or twelve, tightly covered with a shield of black excrementitious matter. Over this is stretched a light canopy of web, in which are entangled a few minute black grains of excrement. The extreme transparency of the egg envelopes as well as of the animal itself affords an unusually favorable opportunity for the study of the changes that precede its birth.

Just before hatching the embryos lie with their backs to the surface of the leaf and are not curled in the egg, but the head only is bent over upon the breast. As the egg-shell is absolutely transparent and the embryo very nearly equally so, all internal changes of form can be plainly seen.

In hatching, the first movement seen is the formation of air bubbles, which pass in rapid succession between the mouth organs and collect in a larger bubble within the head of the embryo. From time to time this larger bubble passes through the constriction of the neck and disappears in the body cavity. The head of the embryo gradually swells, elongates, and distends the elastic egg-shell at the end, until this finally bursts and the young insect protrudes its body, curving upwards and forwards.

Air continues to pass through the neck into the abdomen, which becomes greatly distended and elongated, showing the segments. A muscular movement not connected with the passage of the air bubbles is seen in the frontal part of the head and the occiput is frequently drawn inwards, forming a deep depression.

The bursting of the first larval skin was not witnessed, but it evidently takes place soon after the abdomen is fully distended. The larva remains for many hours in an erect position, with the tip of the body clasped by the egg-shell and the cast larval skin. The head, at first elongate, becomes transverse and there is a general contraction and change of form in all the parts.

After the larva has freed itself from the egg-shell and envelopes, the abdomen is gradually contracted by the exertion of considerable and long-continued muscular effort and changes from a cylindrical to a cordate form.

The process of hatching occupies several days, and the young, as we have seen, make their entrance into the world, like a marsupial, in a somewhat rudimentary condition.

The Orange Psocus lives chiefly upon the leaves of plants, associated in small flocks or families. It passes the greater part of its life hiding under the canopies of web erected over the egg-clusters. Here the mother awaits the appearance of her brood, and here the young insects cluster, sallying forth from time to time with the adult in search of food.

The species breeds continuously in summer and some eggs are hatched even in winter. The adult insects hibernate in protected places, but are more delicate than their northern relative and probably do not extend beyond the region in which the Orange is grown.

The operations of this Psocus are apparently of trifling importance; it is, however, one of the commonest of orange insects and as such attracts considerable attention.

# APPENDICES.

## APPENDIX I.

### *THE MEALY BUG AT ORANGE LAKE, FLORIDA.*

[Extracted from a letter by Jos. Voyle, Gainesville, Fla., June 12, 1884. Reprinted from Bulletin 4, Division of Entomology, U. S. Department of Agriculture, p. 85.]

Having business near Orange Lake during the past week, I visited several orange groves. I found all of the Florida varieties of Scale-insects in abundance. Oranges are already rusty, and the Rust-mite in many places, on both leaves and fruit, in such large numbers as to give a distinct coloration, distinguishable at a distance of ten feet.

But the most destructive insect, at present absorbing all the attention of the orange-growers there, is the Mealy-bug, *Dactylopius destructor*. This insect causes the fruit to rot under the colonies. A favorite place of lodgment is at the stem, under the calyx; the result is, the fruit drops.

I staid there three days to examine methods used and experiment in their destruction.

The cotton y armor repels all watery solutions.

The methods used are: spraying each separate colony with pure kerosene by means of bellows atomizers; and mechanical action—rubbing or pinching each separate colony (by colony I mean the little clusters consisting of from ten to several hundred individuals); this is done by the fingers.

I examined the trees that had been treated with the kerosene spray and found both the leaves and fruit spotted yellow. I was also informed that fruit saved in this way two years ago was useless, having absorbed the odor of kerosene. The effective progress made by the means used is trifling, in consideration of the work to be done. I tried experiments with solutions of murvite sprayed on, but with no good result; then tried kerosene butter, using thick, milky solution of murvite, which combines in exactly the same way as with cow's milk, and found that an effective emulsion could thus be made.

After using and watching the action of this for some time, I saw that the interior insects of a dense mass were protected by the exterior ones; further experiments were made to meet this difficulty. By watching the men at work I saw that nearly every infested orange was handled to turn all of its sides to the eye; that wherever a large colony found lodgment in a fork of twigs or in a depression of the bark they were handled, also that the bunches of Spanish moss (*Tillandsia*) formed formidable breeding places. All of these require force for their dislodgment.

A strong stream of water was tried and proved effective, but laborious, and the insects falling to the ground were not killed.

Experiments with solution of murvite, made under a microscope, showed that in all cases where the solution came into actual contact with the skin of the insect the bug was instantly killed. Acting upon this and the knowledge gained by previous observation and experiment, I tried the effect of a fine, solid stream issuing under pressure, using a solution of murvite, one part, to water two hundred and fifty parts.

The results were excellent; the solution being forced into the colonies broke them up, and coming into contact with the insects killed them, the method of working being one man at the pump, another to guide the stream. The apparatus improvised being badly adapted to the purpose is very awkward. The work, although about four times as fast as with the bellows atomizer, is not adequate to the economical requirements. This method has the merit of no loss by damage to fruit or leaves by the material used; the waste, falling on the leaves and branches, will exterminate both scale-insects and rust-mites, these being plentiful, but neglected in the presence of the more pressing necessity of saving the growing crop from destruction by the Mealy-bug.

TABLE 1.—*Kerosene emulsions.*

| No. of experiment. | No. of emulsion. | Kerosene in the emulsion. | Emulsion diluted with water. | Amount of diluted wash applied. | Date of application. | Date of examination. | Long Scale (*M. gloveri*). | | | | Chaff Scale (*P. pergandii*). | | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Young coccids killed. | Scales containing eggs. | | | Young coccids killed. | Scales containing eggs. | | | |
| | | | | | | | | Eggs, in part killed. | Eggs, all killed. | Eggs, none killed. | | Eggs, in part killed. | Eggs, all killed. | Eggs, none killed. | |
| | | *pr. ct.* | *Parts.* | *Qts.* | | | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | |
| 10 | 2 | 80 | 1 to 16 | 10 | Oct. — | Oct. 22 | 99 | 39 | 61 | 0 | ..... | ..... | ..... | ..... | Bark, leaves, and twigs of lower branches. |
| | | | | | | Oct. 25 | 93 | 58 | 29 | 13 | ..... | ..... | ..... | ..... | Thorns from upper branches. November 10, a few gravid females still living, also a few young scales forming from eggs recently hatched. |
| 10 | 11 | 67 | 1 to 16 | 6 | Nov. 14 | Nov. 17 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Second application effectively cleared the tree of scales; only an occasional gravid scale found alive on upper branches. |
| 11 | 3 | 73 | 1 to 64 | 6 | Oct. 22 | Oct. 25 | 25–30 | ..... | 0 | 99+ | ..... | ..... | ..... | ..... | No appreciable effect upon eggs or mature coccids. |
| 29 | 11 | 67 | 1 to 9½ | 6 | Nov. 14 | Nov. 19 | 71 | 43 | 18 | 39 | ..... | ..... | ..... | ..... | Thickly infested bark of lower limbs. Upper branches give variable results. |
| | | | | | | Dec. 26 | 100 | ..... | 100 | ..... | ..... | ..... | ..... | ..... | Bark, twigs, and leaves from all parts. Prolonged examination; not a living coccid or egg can be found. Mites swarm under the dead scales and have probably completed the work of the wash. |
| 24 | 11 | 67 | 1 to 16 | 6 | Nov. 11 | Nov. 18 | 91 | 37 | 19 | 44 | 63 | 65 | 0 | 35 | |
| 28 | 11 | 67 | 1 to 16 | 6 | Nov. 14 | Nov. 19 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Result about the same as in No. 24, or slightly less effective and variable. |
| 25 | 11 | 67 | 1 to 16 | 4 | Nov. 11 | Nov. 19 | 78 | 29 | 8 | 63 | ..... | ..... | ..... | ..... | Variable; some branches give poor results. Evidently not enough liquid used for thorough application. |
| 31 | 11 | 67 | 1 to 16 | 3 | Nov. 14 | Nov. 18 | ..... | ..... | ..... | ..... | 22 | ..... | 5 | 95 | Small tree, but not sufficient wash used. Effect on Long Scale about equal to No. 25. Lecanium Scales killed only where the spray struck with force |
| 26 | 11 | 67 | 1 to 16 | 2 | Nov. 11 | Nov. 19 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Small tree, but amount of wash applied entirely insufficient. Many branches show no effect. Very few Long Scale killed. |
| 38 | 13 | 65 | 1 to 16 | 6 | Dec. 8 | Dec. 12 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Result about the same as in No 24. Second application four days later. |
| 38 | 13 | 65 | 1 to 16 | 9 | Dec. 12 | Feb. 4 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Almost complete extermination of Long Scale. A few living coccids found upon a twig from upper branches. On the same twig a few living Chaff Scale were also found. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | 10 | 57 | 1 to 16 | 6 | Nov. 4 | Nov. 9 | 25 to 50 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Action very unequal upon different parts of the tree. Examination made too soon after application to show full effect of the wash. |
| 18 | 10 | 57 | 1 to 16 | 6 | Nov. 4 | Nov. 10 | ..... | ..... | ..... | ..... | Few | ..... | ..... | ..... | Effect upon Chaff Scale very slight. On some leaves nearly all killed. |
| | | | | | | Jan. 30 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Tree less infested than formerly and condition much improved, but not cleared of scales. Chaff Scale beginning to increase again. Some Long Scale still living. |
| 20 | 9 | 40 | 1 to 8 | 6 | Nov. 4 | Nov. 10 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Chaff Scale not appreciably affected. Long Scale killed to some extent. *Lecanium hesperidum* not killed. |
| | | | | | | Jan. 30 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Application not effective in clearing the tree. Chaff Scale will soon begin to increase. |
| 16 | 9 | 40 | 1 to 11 | 6 | Nov. 3 | Nov. 9 | 45 | 37 | 14 | 49 | ..... | ..... | ..... | ..... | Leaves and twigs..... } Chaff Scale much less affected. |
| | | | | | | Nov. 9 | 36 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Exposed bark of upper branches. } |
| | | | | | | Nov. 10 | 72 | 20 | 19 | 61 | ..... | ..... | ..... | ..... | Leaves, twigs, and bark of main branches. Chaff Scale less affected; not counted. |
| | | | | | | Nov. 11 | 100 | 40 | 0 | 60 | ..... | ..... | ..... | ..... | A single large leaf. |
| | | | | | | Jan. 25 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Long Scale and Chaff Scale beginning to increase and entering upon a new brood. |
| 19 | 9 | 40 | 1 to 24 | 6 | Nov. 4 | Nov. 10 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Tree infested with Chaff Scale only. Effect on scales scarcely appreciable. |
| | | | | | | Jan. 30 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Application has had little or no effect. Number of living scales has neither increased nor diminished. New brood beginning to hatch. |
| 23 | ..... | ..... | ..... | 6 | Nov. 4 | Nov. 11 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Imperfect emulsion made by churning together one-half pint of kerosene, 12 fluid oz. (?) condensed milk, and 6 quarts water. Application very unequal owing to imperfect mingling of the oil and water. Young of Long Scale killed on some branches and not killed on others. Eggs for the most part uninjured. Some infested leaves show all coccids killed on one side; all living on the other side. |

*Cost of kerosene wash.*—The following is the estimated cost for a standard wash of whale-oil soap and kerosene emulsion containing 67 per cent. of oil, and diluted 1 to 9:

| | |
|---|---|
| Kerosene, 2 gallons, retail at 20 cents | $0.40 |
| Soap, ½ pound, retail at 10 cents | 5 |
| Water, 1 gallon | 0 |
| Emulsion, 3 gallons | 45 |

At wholesale rates, 18 cents for kerosene and 8 cents for soap, three gallons of emulsion cost 40 cents = 13⅓ cents per gallon. One gallon of emulsion = 10 gallons of diluted wash; cost, 15 cents. Cost of wash per gallon, 1½ cents.

With the "Aquapult" pump and "Cyclone" nozzle, four gallons of wash is sufficient for thirty nursery trees of one and two years from the bud. Cost per tree, two-tenth cent.

Trees which have been transplanted and have made two years' average growth in the grove (3 or 4 years from the bud) require about two-thirds of a gallon of wash. Cost, 1 cent per tree. Bearing trees of full size will require from 5 to 10 gallons of wash. Cost, 7 to 15 cents; average about 10 cents per tree.

TABLE 2.—WHALE-OIL SOAP.

In Table 2 are given the results of experiments with solutions of whale-oil soap applied in fine spray to all parts of the trees by means of the aquapult pump. The solutions were all applied hot, being either solid when cool or too thick for spraying through the pump.

TABLE 2.—*Whale-oil soap.*

| No. of experiment. | Whale-oil soap solutions. | | | Date of application. | Date of observation. | Long Scale (*M. gloveri*). | | | | Chaff Scale (*P. pergandii*). | | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soap. | Water. | | | | Young coccids killed. | Scales containing eggs. | | | Young coccids killed. | Scales containing eggs. | | | |
| | | | | | | | Eggs, in part killed. | Eggs, all killed. | Eggs, none killed. | | Eggs, in part killed. | Eggs, all killed. | Eggs, none killed. | |
| | *Lbs.* | *Qts.* | | | | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | |
| 34 | 1 | 4 | 4½ quarts applied hot. | Dec. 6 | Dec. 17 | 100 | 0 | 0 | 100 | 95 (?) | 0 | 0 | 100 | Tree infested with Long Scale and a few scattered Chaff Scale; nearly every coccid, old and young, killed; a very few Chaff Scale still alive; eggs of both scales absolutely uninjured; tree rather large; not enough liquid used. |
| | | | | | Jan. 28 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Long Scale completely exterminated; eggs and young probably destroyed by mites; living Chaff Scale, nearly all young or nearly adult, numerous on some parts. |
| 33 | 1 | 6 | 6 quarts applied hot. | Dec. 6 | Dec. 16 | 100 | 24 | 15 | 61 | ..... | ..... | ..... | ..... | Small tree; very thorough application; at noon in the sun. |
| | | | | | Jan. 28 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Both Long and Chaff Scale completely exterminated upon nearly all parts of the tree; several twigs, however, have escaped thorough wetting, and are still moderately infested with one or both kinds of scale. |
| 35 | 1 | 8 | 8 quarts applied hot. | Dec. 8 | Dec. 17 | 95 | 0 | 0 | 100 | ..... | ..... | ..... | ..... | Tall tree; difficult to cover with liquid; adult female coccids not all killed. |
| | | | | | Jan. 28 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | A few individual Long Scale found alive on some branches; 1 or 2 per cent. living. |
| 36 | 1 | 10 | 5 quarts applied hot. | Dec. 8 | Dec. 26 | 90 | 0 | 0 | 100 | ..... | ..... | ..... | ..... | Small tree; Long Scale which have not completed the first molt are all killed; the proportions given include coccids from passed first molt to adult; a few Chaff Scale seen, all living; no gravid female coccids killed. |
| 37 | 1 | 12 | 6 quarts applied hot. | Dec. 8 | Dec. 26 | 70 | 0 | 0 | 100 | 0 (?) | 0 | 0 | 100 | Small tree; thorough application; a few Chaff Scale intermingled seem not to have been affected. |

TABLE 3.—LYE SOLUTIONS.

The following is a synopsis of experiments with potash and soda in caustic solutions:

*Experiments with potash.—Experiment No.* 90.—Solution, 1¼ pounds potash to 1 gallon water. Applied in fine spray to two thrifty young trees, about four years old. Leaves and tender shoots wilted visibly and changed color during the application, showing, a few minutes later, spots of brown. Two days after the application all the leaves were dead and dried up as if by fire, and remained adhering to the branches. Young growth entirely killed and pitted with holes. Three weeks later all branches under one inch in diameter were found to be entirely killed, the bark of larger branches partly destroyed, the bark of trunk blackened and hardened, but not destroyed. Upon the latter buds had begun to appear. Upon those portions of the tree where the bark was entirely destroyed the insects themselves were destroyed, but one-tenth of the scales upon the dead bark contained living eggs. Where the bark was not entirely destroyed half of the Coccids and more than half of their eggs escaped. The tops of both trees were killed and their shape and symmetry ruined. A 40 per cent. kerosene emulsion would have been as effective in destroying the Scale-insect, and would have had no appreciable effect on the tree. A 67 per cent. emulsion, which would have exterminated the insects, would have partially defoliated the most thickly infested branches, without affecting the vigorous portions of the tree.

*Experiment No.* 91.—Solution, 1 pound potash to 1 gallon water. Applied to two small trees very badly infested with Scale-insects. Owing to the enfeebled condition of the trees, the effect of the lye was as severe as in the preceding experiment. Five weeks later one of the trees was recovering, the other dying, and Scale-insects in both cases increasing.

*Experiment No.* 94.—Solution, two-thirds pound potash to 1 gallon water. Applied to several young trees. Nearly all the leaves dropped and many branches killed.

*Experiment No.* 92.—Solution, one-half pound potash to 1 gallon water. Applied to two small trees badly infested with Long Scale. Both trees badly, one completely, defoliated. Tender bark and smaller branches killed. Four or five weeks later the trees were recovering, but young brood of Scale-insect had thickly coated all the living branches.

*Experiment No.* 95.—Solution, four-tenths pound potash to 1 gallon water. Applied to a tree of medium size and in good condition. Great injury to foliage and tender bark. One month later the trees were recovering, but Scale-insect increasing.

*Experiment No.* 93.—Solution, three-tenths pound potash to one gallon water. Devitalized branches completely defoliated; other portions less severely affected. Bark blackened and hardened. One month later trees recovering; Scale-insect not dimin-diminished in numbers.

*Experiment No.* 96.—Solution, one-fourth pound potash to 1 gallon water. Applied to a vigorous tree. Tree not severely defoliated. Four weeks later Scale-insect increasing.

*Experiment No.* 86.—Solution, one-sixth pound potash to 1 gallon water. Applied to a tree rather badly infested, but still vigorous. Tree slightly defoliated. Scale-insect not checked and no eggs killed.

*Experiments with soda lye.*—The strongest application of soda lye, two-thirds pound to 1 gallon water, was not more severe in its effects upon the tree than one-half this amount of potash applied in Experiment No. 93. The bark was blackened, but not destroyed, and the tree was severely defoliated. The application had no permanent effect in removing the Scale-insects, but these were afterwards destroyed by an application of kerosene emulsion, and the tree in consequence fully recovered its vigor. The remaining experiments with soda lye—1 pound to 2, 1 pound to 2½, and 1 pound to 3 gallons of water, respectively (Nos. 43, 44, and 45)—failed to check the increase of the Scale-insect. One year later these trees had lost instead of adding to their growth, and appeared to be in dying condition, the continued presence of the insects having prevented a recovery from the effects of the lye. The Scale-insects were subsequently removed by applications of kerosene, and the trees began to improve rapidly.

TABLE 3.—*Lye solutions.*

| Number of experiment. | Concentrated lye diluted with water. | Amount of solid lye used in single application. | Amount of diluted wash applied. | Date of application. | Date of examination. | Long Scale (*M. gloveri*). | | | | Chaff Scale. (*P. pergandii*.) | | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Young coccids killed. | Scales containing eggs. | | | Young coccids killed. | Scales containing eggs. | | | |
| | | | | | | | Eggs, in part killed. | Eggs, all killed. | Eggs, none killed. | | Eggs, in part killed. | Eggs, all killed. | Eggs, none killed. | |
| | *Strength of the solution.* | *lbs.* | *qts.* | | | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | |
| 42 | Soda lye, 1 lb. to 6 qts. | 1 | 6 | Dec. 31 | Jan. 20 | 37 | 0 | 0 | 100 | ..... | ..... | ..... | ..... | Only a few Chaff Scales examined; all of them alive. |
| 43 | Soda lye, 1 lb. to 8 qts. | 1 | 8 | Jan. 2 | Jan. 9 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Long Scale only. No appreciable result. |
| 44 | Soda lye, 1 lb. to 10 qts. | ½ | 5 | Jan. 2 | Jan. 9 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | Long and Chaff Scale together. No result whatever. |
| 45 | Soda lye, 1 lb. to 12 qts. | ½ | 6 | Jan. 2 | Jan. 9 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 100 | Do. |
| 90 | Potash lye, 1 lb. to 2½ qts. | 1½ | 4 | May 18 | June 7 | 94 | 4 | 89 | 7 | ..... | ..... | ..... | ..... | All small branches killed, bark of trunk burned and hardened, but not destroyed, pushing out adventitious buds. Upon portions where bark is utterly destroyed 8 per cent. of the scales have eggs all alive. |
| | | | | | June 7 | 55 | 31 | 11 | 58 | 60 | 50 | 0 | 50 | |
| 91 | Potash lye, 1 lb. to 4 qts. | 1 | 4 | May 31 | June 6 | 88 | 38 | 12 | 50 | 18 | 6 | 0 | 94 | Tree badly injured, completely defoliated and killed back to larger branches. |
| | | | | | June 5 | ..... | ..... | ..... | ..... | 25 | 5 | 0 | 95 | |
| | | | | | July 4 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Tree reduced to trunk and one living branch, the latter covered with new brood of scale. |
| 94 | Potash lye, 1 lb. to 6 qts. | 3 | 18 | June 22 | July 2 | 78 | 43 | 10 | 47 | ..... | ..... | ..... | ..... | Several trees. Results unequal. |
| | | | | | July 3 | ..... | ..... | ..... | ..... | 46 | 12 | 0 | 88 | |
| 92 | Potash lye, 1 lb. to 8 qts. | ½ | 4 | May 31 | June 6 | 96 | 32 | 0 | 68 | ..... | ..... | ..... | ..... | July 4. Two trees, branches more or less killed back; trees, however, recovering. Living branches thickly coated with forming brood of Long Scale. Application not effective. |
| 95 | Potash lye, 1 lb. to 10 qts. | ⅖ | 5 | July 22 | July 3 | 78 | 20 | 0 | 80 | ..... | ..... | ..... | ..... | Chaff Scale very slightly affected. Eggs all alive. |
| 93 | Potash lye, 1 lb. to 13½ qts. | $\frac{2}{13}$ | 4 | May 31 | June 6 | 70 | 40 | 0 | 60 | 40 | 4 | 0 | 96 | Adult females of Long Scale part killed. Females of Chaff Scale not killed. July 4 trees recovering, Scales as bad as before. |
| 96 | Potash lye, 1 lb. to 16 qts. | ¼ | 4 | June 22 | July 3 | ..... | ..... | ..... | ..... | 15 | 0 | 0 | 100 | Few Long Scales examined, few or no eggs killed. |
| | | | | | July 19 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Scales increasing. No appreciable effect. |
| 86 | Potash lye, 1 lb. to 24 qts. | ¼ | 6 | May 3 | May 7 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | A few young killed. Eggs hatching. |
| | | | | | July 5 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Tree covered with new brood of Long Scale. No effect. |

TABLE 4.—CRUDE CARBOLIC ACID (OIL OF CREOSOTE).

In Table 4 are given results of experiments with carbolic acid in solution a bined with other substances.

In experiment No. 27, 9 fluid ounces of carbolic acid was applied to a sin about five years old. The tree, which was badly infested with Long Scale, many branches dead and dying, was severely defoliated, and lost some m branches, but recovered in six weeks and pushed out new growth in midwint

In experiment No. 30 a pint measure of crumbled carbolic soap was applie actual amount of acid contained in this soap did not exceed 2 fluid ounces. termination of Long Scale was complete. The tree, which was very badly and in poor condition, was almost completely defoliated and lost half its b but recovered very rapidly and pushed out new leaves within thirty days. ( 25.)

In experiment No. 21 the other substances added to the carbolic solution i the injury to the foliage of the tree and it was very severely checked, but ent covered and was stimulated to vigorous growth at a time when all surroundi were dormant.

In the remaining experiments, 13, 14, 15, and 12, the quantity of carbolic a was not sufficient to kill the Scale-insects. The effect upon the trees was a slight.

TABLE 4.—*Carbolic acid.*

| Number. | Carbolic acid; amount used in single application. | | Diluted with water. | Amount of diluted wash applied. | Date of application. | Date of examination. | Long Scale (*M. gloveri*). | | | | Chaff Scale (*P. pergandii*). | | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Young coccids killed. | Scales containing eggs. | | | Young coccids killed. | Scales containing eggs. | | | |
| | | | | | | | | Eggs, in part killed. | Eggs, all killed. | Eggs, none killed. | | Eggs, in part killed. | Eggs, all killed. | Eggs, none killed. | |
| | | | *Qts.* | *Qts.* | | | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | |
| 46 | ..... | [Continued] ..... | ..... | ..... | ..... | Feb. 2 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Living eggs and young scales found on both trees. Long Scale slightly checked; Chaff Scale not at all. |
| 21 | 4½ fl. oz.. | Dissolved in soap, 2 ounces; hot water, 12 ounces; together with silicate of soda, 13 fl. ounces; water, 12 ounces; urine, 7 fl. oz. | 4 | 5+ | Nov. 7 | Nov. 10<br>Nov. 19 | 91<br>99 | 56<br>..... | 0<br>..... | 44<br>..... | ..... | ..... | ..... | ..... | Many scales full of dead larvæ which have hatched since application, but unable to issue. In many scales the eggs are partly or all killed; mother coccids in many cases still alive. Scales severely checked; no new scales forming. |
| 13 | 2 fluid oz.. | Emulsified with condensed milk, 4 fl. oz.; water, 1 oz. | 5 | 5+ | Oct. 26 | Oct. 31 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Tree infested with Long Scale. No appreciable effect upon the scales. |
| 14 | 1.13 fl. oz.. | Emulsified with sour condensed milk, 78 pr. ct.; to creosote, 22 pr. ct. | 6 | 6 | Oct. 31 | Nov. 5 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Long Scale. No appreciable effect. |
| 15 | ⅛ fl. oz.. | Emulsified together with 2.7 fluid oz. of kerosene and 2.64 fluid oz. of sour milk curds.<br>Oil creosote.....14 pr. ct.<br>Oil kerosene .....42 pr. ct.<br>Curds of milk.....44 pr. ct. | 6 | 6 | Oct. 31 | Nov. 5 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Long Scale very slightly affected. Not over 20 per cent. of the young scales killed. No mature females and no eggs killed. |
| 12 | ½ fluid oz. | Solution in water, made by triturating 1 fl. oz. creosote with 2 oz. carb. magnesia and filtering in 1 quart water. | 2 | 2 | Oct. 25 | Nov. 2 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Long and Chaff Scale. No effect whatever. |

TABLE 5.—BISULPHIDE OF CARBON.

table 5 are given the results of several experiments with this insecticide. The ion, of which the ingredients are given in the table, was formed by beating to- r with a spatula the carbon and lard oil and then adding the milk and water, nulsifying in the same manner.

trees in experiments 40 and 41 were very severly checked, although not seriously l, and all subsequently recovered. In experiment 39 the mixture was applied a rain, and was entirely without effect upon the tree or scale.

TABLE 5.—*Bisulphide of carbon emulsion.*

[Bispulph. carb., 56 per cent.; lard oil, 19 per cent.; condensed milk, 6 per cent.: water, 19 per cent.]

| Number of experiment. | Amount of bisulphide used in single application. | | Diluted with water. | Amount of diluted wash applied. | Date of application. | Date of examination. | Long Scale (*M. gloverii*). | | | | Chaff Scale. (*P. pergandii*). | | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Young coccids killed. | Scales containing eggs. | | | Young coccids killed. | Scales containing eggs. | | | |
| | | | | | | | | Eggs, none killed. | Eggs, all killed. | Eggs, in part killed. | | Eggs, in part killed. | Eggs, all killed. | Eggs, none killed. | |
| | | | *Qts.* | *Qts.* | | | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* | |
| 41 | 9 fluid oz.. | In emulsion, 16 fluid oz.... | 5½ | 6 | Dec. 31 | Jan. 20 | 52 | 0 | 0 | 100 | ..... | ..... | ..... | ..... | Very tall tree. Application made on a windy day and upper branches not thoroughly sprayed; gives varying results, some young and nearly all eggs alive. Other parts of tree have been entirely cleared of living young, but a large proportion of eggs escape. |
| | | | | | | | 100 | 35 | 43 | 22 | ..... | ..... | ..... | ..... | (*a*) Thorn from upper branches. Long Scale. Leaves, thorns, and twigs from lower branches Gravid females of Long Scale all killed. A few Chaff Scale examined; coccids killed, but eggs alive. |
| 40 | 5.6 fluid oz. | In emulsion, 10 fluid oz..... | 6 | 4<br>2 | Dec. 31<br>Dec. 31 | Jan. 21<br>Jan. 21 | 100 | 3 | 96 | 1 | 97 | 0 | 98 | 2 | Two trees sprayed, one very small; both infested with Long Scale and Chaff Scale together. Trees nearly cleared of scale in part by the aid of parasites. Application more thorough than No. 41. |
| 39 | 3+ fluid oz. | In emulsion, 6 fluid oz..... | 6 | 6 | Dec. 15 | Dec. 26 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Applied in rain on windy day; not a satisfactory application. No eggs, and apparently no young coccids killed. Examination January 25 gave same results; scales increasing. |

TABLE 6.—SILICATE OF SODA.

Table 6 gives the results of a single experiment in which silicate of soda, in the form of a thick liquid, was diluted ten times and applied in fine spray.

In other trials, with stronger solutions, the best result obtained was 80 per cent. of the young Coccids killed, and trees were cleared of scale by repeated applications at intervals of several weeks; but in these cases the bark was hardened and the growth of the trees somewhat checked.

TABLE 6.—*Silicate of soda.*

| Number of experiment. | Amount used in single application. | | Diluted with water. | Amount of diluted wash applied. | Date of application. | Date of examination. | Long Scale (*M. gloveri*). | | | Chaff Scale (*P. peryandii*). | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Young coccids killed. | Scales containing eggs. | | Young coccids killed. | Scales containing eggs. | | |
| | | | | | | | | Eggs, in part killed. | Eggs, all killed. Eggs, none killed. | | Eggs, in part killed. | Eggs, all killed. Eggs, none killed. | |
| | | | *Qts.* | *Qts.* | | | *pr. ct.* | *pr. ct.* | *pr. ct.* *pr. ct.* | *pr. ct.* | *pr. ct.* | *pr. ct.* *pr. ct.* | |
| 22 | 16 fluid oz. | Silicate of soda, diluted 1 to 9. | 4½ | 5 | Nov. 7 | Nov. 10 | 43 | 0 | 0 100 | ..... | ..... | ..... ..... | Gravid females and eggs not injured. Chaff Scale; young slightly affected, eggs not at all. |

# APPENDIX III.

## *THE COITION OF BAG WORMS.*

**The following is an extract from an account of certain Australian Bag-worms, by William W. Saunders, as read before the Entomological Society of London, February 1, 1847.***

"*August* 30.—On this day I first observed a yellowish-white substance protruding at the lower end of the largest cases, which upon close examination proved to be a portion of the females in the imago state, one-third of their bodies being exposed. About an hour afterward, examining the cases again, I found the females had receded, and in opening a case the female moth became evident within, and thus they emerge and recede as occasion may require. The female is a large apterous moth, with a very little of the ordinary appearance of an insect of the moth kind. The length is about 1¼ inches, diameter full half an inch, color yellowish white, fawn, or buff; head and three first segments of the body naked and glossy on the upper part; feet very short. Antennæ none, or at least not visible to the unassisted eye; anal segment of the body clothed all round with a dense covering of silky down [42] of a deeper color than the rest of the body; ovipositor well developed.

"*September* 5.—Examined some of the females, no males having yet appeared. Two or three were dead; one nearly so, having deposited a great number of ova in the pupa case, which were enveloped in a short silky material. When the female has deposited all her ova, she is literally nothing but thin skin, which soon desiccates, leaving room for the young larvæ to pass. I have examined other species of *Oiketicus*, and find all the females are apterous.

"*September* 20.—A male imago appeared this morning. It had been in active operation a good while, as evinced by its wings, being much broken at the tips and otherwise much abraded. It is an insect of very peculiar construction, and seems to have some affinity with *Zeuzera*. It has the extraordinary power of extending the abdomen to 2 inches in length, and of turning and twisting it in all directions. When in this state it has alternate rings of black and yellow, with a curious appendage at the extremity. The male appears very eager to accomplish the grand object of nature, namely, the continuation of its species, as its existence appears to be of short duration. The large fat or rather distended females have not room to turn their bodies so as to present the generative organs conviently to the male, consequently the immense development of the abdomen in the males is of the greatest importance; but it appears very extraordinary that the head of the female should be inverted, when it is known that she never emerges from the case unless by accidentally falling therefrom, which position obliges the male when in the act of coition to stretch his abdomen all along the side of the female full 1¼ inches. This peculiarity appears to me to be the design of the all-wise Creator, in order to afford a secure place for the defenseless larvæ, viz, that of the pupa-case of their parent, from which they emerge after the disappearance of their mother's body, and immediately form themselves silken cases covered with small pieces of anything they can procure, arranged in every respect like the larger ones."

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* Remarks on the habits and economy of a species of *Oiketicus* found on shrubs in the vicinity of Sydney, N. S. W., by W. W. Saunders, esq., F. L. S., &c. Drawn up from notes furnished by W. Stephenson, esq. Transactions of the Entomological Society of London, Vol. V. 1847–1849. pp. 40–33.

Recently Professor Riley has given a more detailed and exact account of the manner by which the act of coition takes place. A portion of his article which was published in the Scientific American Supplement of April 3, 1878, and republished in the Proceedings of the Biological Society of Washington, Vol. ii, 1882–'4, p. 81, is here reproduced:

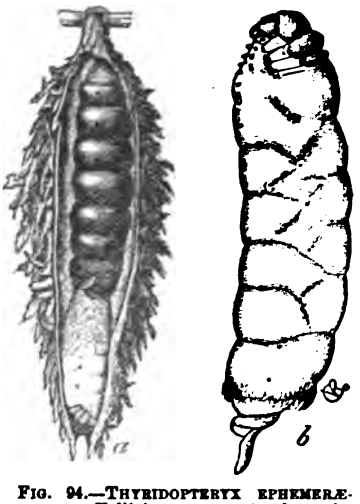


FIG. 94.—THYRIDOPTERYX EPHEMERÆFORMIS: *a*, Follicle cut open to show the manner in which the female works from her puparium and reaches the end of the bag, natural size; *b*, female extracted from her case, enlarged. (After Riley.)

"We have seen that, by means of the partial elongation of her puparium and her partial extraction therefrom, the female is able to reach with her head to the extreme lower end of her follicle, causing, in doing so, the narrow elastic portion of the follicle to bulge, and the orifice to open more or less, as it repeatedly did while the larva was yet feeding, whenever the excrement had to be expelled. Fig. 94, *a*, shows a follicle cut open so as to exhibit the elongated puparium, and the female extended from it as she awaits the male; *b* represents this degraded female more in detail. A cursory examination of the male shows the genital armature, which is always exposed, to consist of (1) a brown, horny, bilobed piece, broadening about the middle, narrowing to and notched at tip, concave, and furnished with a tuft of dark hairs at tip inside; (2) a rigid brown sheath, upon which play (3) the genital hooks or clasps, which are also concave inside, strongly bifid at tip, the inner finger furnished with hairs, the outer produced to an obtuse angle near tip, and generally unarmed (Fig. 95, *e*). In repose, this armature appears as in Fig. 95, *c*, from beneath, and as at *d*, from above, and is well adapted to prying into the opening of the follicle. The male abdomen is telescopically extensile, while the tip easily bends or curves in any direction, but most naturally beneath, as at *b*, where it is represented enlarged about six times, and with all the genital parts expanded; *k*, the fixed outer sheath; *f*, the clasps; *g*, a pale membranous sheath upon which the præputium (*h*) plays, as on the finger of a glove; *i*, the fleshy elastic penis, armed with retorse hairs, and capable of extending to nearly one-fourth of an inch; *j*, showing the end still more fully enlarged. With this exposition of details, not easily observed or generally understood, the act of fecundation is no longer a mystery."

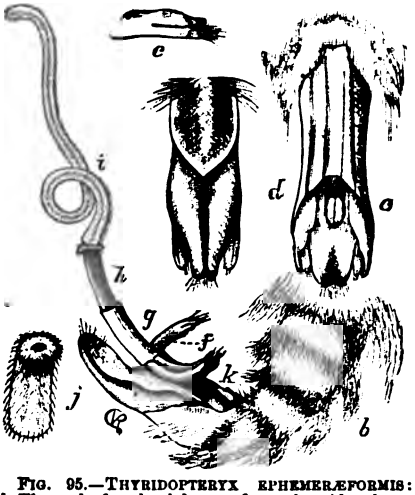


FIG. 95.—THYRIDOPTERYX EPHEMERÆFORMIS: *b*, The end of male abdomen from the side, showing genitalia extended; *c*, genitalia in repose, ventral view; *d*, do., dorsal view; *e*, tip of bifid clasp; *j*, tip of penis; all enlarged. (After Riley.)

# NOTES.

NOTE 1 (p. 59).—Mr. Howard states that this Tetrastichus has never since been bred, and that the material is too poor for determination. April 18, 1885, I bred two additional species of parasites from the Florida Ceroplastes at Crescent City, which were determined by Mr. Howard as (1) *Coccophagus vividus* Howard (see Bulletin 5, Division of Entomology, U. S. Dept. Agr., page 24, species 37) which I had previously bred from *Lecanium hesperidum*, on Orange, at Crescent City. (2) A species of *Encyrtus* represented by one ♂ which was mounted in balsam and so badly crushed as to admit only of a generic determination.

NOTE 2 (pp. 69 and 77).—In looking up the saved material in order that this species might be determined, but a single crippled and inferior specimen was found, and Professor Riley prefers not to describe it for the present from this unsatisfactory specimen.

NOTE 3 (p. 79).—This parasite was handed to Mr. Howard, who has given me the following concerning it:

"While at first glance I determined the *Leptocorisa* egg-parasite for you as a species of *Telenomus*, a more careful subsequent study, and a comparison with a number of Mayr's types of this genus, show that it belongs rather to the allied genus *Hadronotus* of Foerster. The great majority of the species of the subfamily Scelioninæ, to which these two genera belong, are egg-parasites. This species may be described as follows:

"HADRONOTUS LEPTOCORISÆ n. sp.

"*Female.*—Length, 1.4$^{mm}$; expanse, 2.5$^{mm}$. Head and face evenly covered with small round punctures, except in the facial impression, which is transversely striate; antennæ subclavate; lateral ocelli nearly touching the margins of the eyes. Mesonotum a trifle smoother than the head and furnished with a very fine white pubescence. First segment of the abdomen dorsally longitudinally striate; remaining segments closely covered with fine round punctures; ventral surface sparsely punctate. Color, black; scape, brown; all coxæ, black; all trochanters, femora, tibiæ, and tarsi, light brown; mandibles and wing-veins, light brown.

"*Male.*—Length, 1.3$^{mm}$; expanse 2.6$^{mm}$. Antennæ filiform. In other characters resembling the ♀."

"Described from many ♂ and ♀ specimens, bred from the eggs of *Leptocorisa tipuloides*, at Crescent City, Fla., by H. G. Hubbard."

NOTE 4 (p. 80).—These bugs belong to the genus *Rhinacloa*, but the species is undetermined.

NOTE 5 (p 81).—This species is so far undetermined. It is a beautiful and well-marked species, the prevailing color being brown. The mesoscutum has two yellow stripes converging posteriorly, the mesoscutellum is entirely yellow, the metascutellum is marked with yellowish, and the abdomen has yellow rings.

Just as these notes are going to press, I am able to add the following concerning this species, received from Mr. Cresson:

"The specimen arrived minus its abdomen, but judging from what is left it seems to belong to the genus *Hemiteles*. I have looked over the material belonging to that

genus in the society's collection, and do not find anything there agreeing with your specimen. I do not think it has been described, but as I have never worked up the genus, I cannot say definitely that it is new."

NOTES 6, 7, 8, 9, and 10 (pp. 83 and 84).—These mites were mounted in balsam for subsequent study by Professor Riley, with a view of possible determination. He has kindly examined them and furnished the following notes and descriptions:

"The so-called 'Hairy Orange Mite' (Note 6) is one of the 'Harvest-mites' belonging to the section *Eupodidæ* and comes nearer to *Penthalodes* Murray than to any other defined genus, having 6-jointed legs of about equal length. It may be described as follows:

"PENTHALODES MYTILASPIDIS n. sp. Average length, 0.3mm. Broadly oval; abdomen tapering to a point. Color dark red, with pale hairs. Head distinctly separated, narrow, elongate, conical. Mandibles scissor-like, projecting. Palpi inserted at apex of cephalothorax, close to the head, stout, 4-jointed, the first joint stoutest, first and second of about equal length, third shortest, the fourth ending in a stout, curved claw at the base of which an elongate oval thumb is inserted. Eyes barely discernible near the side of the cephalothorax between the first and second pairs of legs. Cephalothorax rounded in front, merging posteriorly into the abdomen, so as to leave no distinct division except in shrunken specimens. Surrounded by rather long and stout bristles, about 8 on each side, and with two rows of similar bristles dorsally. Legs about equal in length, the first pair very slightly longest; third joint longest. Claws 3, much curved at tip, the middle one curved upwards.

"Of the 'Spear-head Mite' (note 7) the mounted specimens are unfit for study and no determination can be made of them.

"The so-called 'Spotted Mite' (note 8) is also represented by such poor specimens from the Orange Coccidæ that they could not be used for determination, but I have obtained a closely-related species from twigs containing the eggs of *Cicada septendecim*, and have thus been able to make out its characters. It belongs to the Beetle-mites or Oribatidæ, and the one-clawed section; but it cannot strictly be placed in any defined genus. As I would not care to erect a new genus in these fragmentary notes, the species may be described under the genus *Hermannia*, to which it approaches nearest structurally, though bearing no great resemblance to the commoner species of that genus.

"HERMANNIA (?) TRINEBULOSA n. sp.—Length, 0.38mm. Color whitish, pellucid. Pyriform, surface apparently smooth and polished; three dusky abdominal patches, one large and central, and one at each lower side with a central, elongate-ovoid corneous plate; two dorsal rows of rather long hairs, with a few others at sides, a rather stouter one on each shoulder, and three anal pairs, the intermediate or second pair longest—all very minutely barbed. Cephalothorax broadly conical, bluntly rounded in front, separated from the body by a distinct transverse suture; on each side towards the base is a conspicuous, strongly clavate bristle. Palpi 6-jointed, the 2nd joint as long as the others together. All legs of about equal length, 6-jointed; terminal joint longest, tapering quite suddenly from about the middle to the end, especially in the posterior pair of legs. Claw simple, large, and strongly curved. All legs sparsely beset with rather long, simple bristles, which are most numerous on the terminal joint.

"Of figs. 39 and 40 (notes 9 and 10) the slides are not to be found, but, judging from the figures, the former is a *Tyroglyphus*, the species of which are very commonly found preying on animal matter, and the latter a *Sejus*, one of the Gamasid genera. I should not care to describe them by name without study of the specimens."

NOTE 11 (p. 98).—Prof. H. W. Wiley, chemist, U. S. Department of Agriculture, gives the following reactions of sulphur upon lime, treated with boiling water.

"Depending on the proportion of sulphur used, the products may be considered as follows:

$$3\,CaO + S_6 = 2\,CaS_2 + CaS_2O_3$$

*Calcium disulphide + Calcium thiosulphate*

"Or, with a greater amount of sulphur,

$$3\,CaO + S_{13} = 2\,CaS_5 + CaS_2O_3$$

*Calcium pentasulphide + Calcium thiosulphate.*

"In fact, probably both reactions go on at once, and even more complicated ones.

"The reaction of lime in the act of slaking on sulphur would probably be small, owing to the short time during which the heat would continue."

NOTE 12 (p. 153.)—The specimens of this parasite were turned over to Mr. Howard, who has given me the following description:

"MIOTROPIS PLATYNOTÆ n. sp.

"*Female.*—Length, 1.65mm; expanse, 3.0mm. Head broader than thorax; vertex broad; ocelli very close together; scape reaching almost to vertex. Pro and mesoscutum somewhat rugose; mesoscutellum nearly smooth; metathoracic carina well marked. Hind coxæ with an external longitudinal groove. Abdomen moderately long oval, flattened. Color uniform honey-yellow (in dry specimens; Mr. Hubbard, in his general description, says: "Honey yellow; head, lemon-yellow"); eyes and ocelli, dark red; tip of scape, dorsal surface of pedicel, and all of flagellum, dusky; two large occipital dark spots, sometimes confluent; abdomen brownish at lateral border and with a brownish central spot varying in size; legs, light honey-yellow.

"*Male.*—Slightly smaller than female; abdomen widening from base to near extremity. Face with two converging black streaks from insertion of antennæ to middle ocellus; hind tibiæ with a distinct dusky tinge near extremity; abdomen more distinctly edged with brown and with a central translucent spot.

"Described from 5 ♂, 1 ♀; bred from larva of *Platynota rostrana*, at Crescent City, Fla., in September, by H. G. Hubbard.

"This species will probably ultimately form a new genus, as in the structure of the thorax at least it differs from the descriptions of *Miotropis*. It is, however, more nearly related to this genus than to any other Elachistid genus, and I therefore place it here temporarily."

NOTE 13 (p. 153).—This species was also referred to Mr. Howard, who describes it as follows:

"GONIOZUS HUBBARDI n. sp.

"*Female.*—Length, 2.4mm; expanse, 4.4mm. Face and notum very sparsely punctured and furnished with fine white pile; also delicately shagreened in addition to the round punctures. Abdomen very smooth and shining and ovate-acuminate in form; somewhat pilose, especially towards tip. Wings clear; stigma brown, with a hyaline spot at its center; stigmal cell nearly complete. Color black; all legs, including coxæ, honey-yellow; mouth-parts and antennæ honey-yellow.

"Described from 1 ♀ specimen, bred in October, from the larva of *Platynota rostrana*, at Crescent City, Fla., by H. G. Hubbard, for whom I have named the species."

NOTE 14 (p. 154).—This is evidently a dark form of *Cacœcia obsoletana* Walk. which Professor Riley has bred from oak, but it doubtless has several food-plants, as it is allied to the wide-spread and polyphagic *Cacœcia rosaceana* Harr., which feeds on rose, apple, peach, cherry, yellow birch, plum, cotton, clover, honeysuckle, bean, strawberry, *Negundo aceroides*, *Cornus stolonifera* and *Cratægus* spp.

NOTE 15 (p. 178).—The single specimen of this species preserved is badly damaged and minus all the head parts. It appears to be a *Blastobasis*, like the species which immediately precedes it.

NOTE 16 (p. 186).—This parasite was referred to Mr. Howard, who has given me the following:

"PACHYNEURON ANTHOMYIÆ n. sp.

"*Female.*—Length, 1.4mm; expanse, 2.6mm; greatest width of fore wing 0.56mm. Head, face, and thorax delicately shagreened; antennæ inserted at the middle of the face; scape reaching to the first ocellus; club flattened, oval. Petiole of the abdomen slightly punctured. Abdomen flattened, oval. Subcostal vein of fore wing with seven strong forward-directed bristles. Mesoscutellum not especially prominent. Rear coxæ with four or five bristles above at tip. Color, very dark metallic green; scape of antennæ honey-yellow; pedicel dark above, yellow below; flagellum light brown; all legs honey-yellow; front and middle coxæ brownish above, verging upon metallic green at base; hind coxæ metallic green; all femora brownish in the middle, honey-yellow at either extremity; wing veins dark brown.

*Male.*—Length, 1.1mm; expanse, 2.5mm. Antennæ slenderer than in the ♀ and markedly pilose. Abdomen flattened, spatulate in form. Color, metallic green, lighter and more brilliant than in the female; legs of a brighter, nearly lemon, yellow; femora without the brownish central band.

## PLATE VIII.

ORANGE RUST.

(After Hubbard.)

## PLATE IX.

KATYDIDS ON ORANGE.

(After Comstock.)

FIG. 1. *Microcentrum retinerve*: 1, adult; 1*a*, eggs; 1*b*, young, natural size.

FIG. 2. *Eupelmus mirabilis*: 2, female; 2*a*, male, enlarged; 2*b*, eggs of katydid from which *E. mirabilis* has emerged, natural size.

## PLATE X.

ORANGE DOG.

(Original.)

FIG. 1. *Papilio cresphontes*, adult.

FIG. 2. *Papilio cresphontes*, full-grown larva, natural size.

FIG. 3. *Papilio cresphontes*, head of full-grown larva with horns extended, from the side, natural size.

FIG. 4. *Papilio cresphontes*, head of full-grown larva with horns extended, from the front, natural size.

FIG. 5. *Papilio cresphontes*, chrysalis suspended on twig, natural size.

## PLATE XI.

MISCELLANEOUS ORANGE INSECTS.

(Original.)

FIG. 1. *Papilio cresphontes*, twig of orange, showing eggs and young larva, natural size.

FIG. 2. *Papilio cresphontes*, larva, one-third grown, natural size.

FIG. 3. *Empretia stimulea*, full-grown larva, natural size.

FIG. 4. *Dysdercus suturellus*, enlarged one-third.

FIG. 5. *Thrips tritici* on Orange blossoms, natural size.

## PLATE XII.

BAG-WORMS AND PARASITES.

FIG. 1. *Thyridopteryx ephemeræformis*: *a*, larva; *b*, pupa of male; *c*, adult female; *d*, adult male; *e*, sack of female cut open, showing pupa-case and eggs; *f*, larva carrying case; *g*, sacks of young, natural size. (After Riley.)

FIG. 2. Young Bag-worms (*Oiketicus*), forming their sacks, *a* to *e*; *f*, sack of young completed, enlarged. (Original.)

FIG. 3. *Hemiteles thyridopterigis*: *a*, male; *b*, female; *c*, sack of bag-worm cut open, showing cocoons of parasite, natural size. (After Riley.)

FIG. 4. *Pimpla conquisitor*, slightly enlarged. (After Comstock.)

FIG. 5. *Cryptus inquisitor*. (After Riley.)

## PLATE XIII.

MISCELLANEOUS ORANGE INSECTS.

(Original.)

FIG. 1. *Anaxylis demissalis*, web-tangle of the caterpillars and spider, natural size: *a*, larva; *b*, moth, slightly enlarged.

FIG. 2. Aphis of the Orange: *a*, wingless female; *b*, winged female; *c*, parasitized female, greatly enlarged; *d*, colony on leaf, all parasitized, slightly enlarged.

FIG. 3. *Trioxys testaceipes*, greatly enlarged.

## PLATE XIV.

MISCELLANEOUS ORANGE INSECTS.

(Original.)

FIG. 1. *Hypothenemus eruditus*, enlarged.

FIG. 2. *Leptostylus biustus*: *a*, beetle, enlarged; *b*, work and cocoon cell, natural size.

FIG. 3. *Hyperplatys maculatus*, enlarged.

FIG. 4. *Midas clavatus*, natural size. (Re-drawn from Harris.)

FIG. 5. *Carpophilus mutilatus*, enlarged.

FIG. 6. *Epuræa æstiva*, enlarged.

FIG. 7. Pomace-fly of the Orange: *a*, adult fly; *b*, larva; *c*, puparium, all enlarged.

FIG. 8. *Chrysobothris chrysoela*, enlarged.

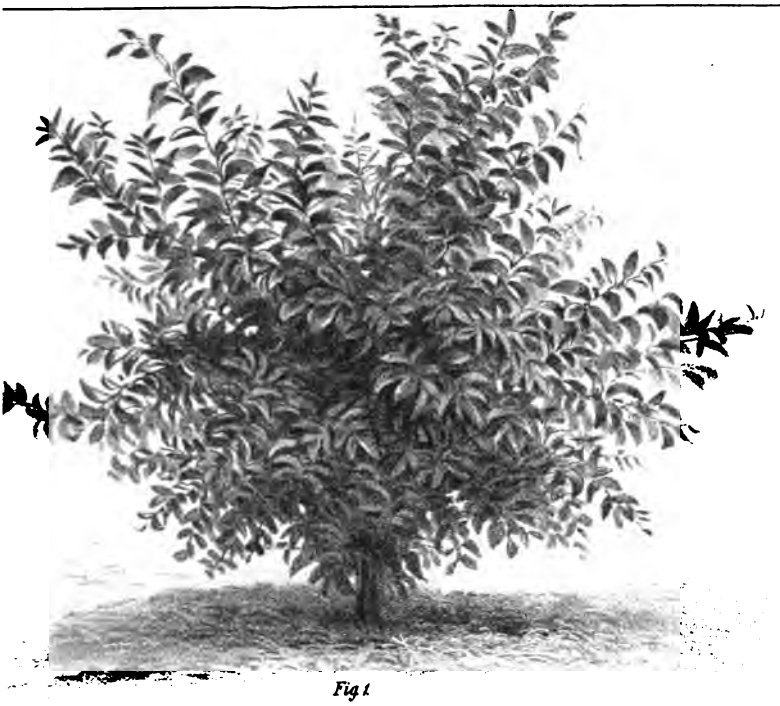

Fig 1

Fig 2

ISAAC VRIEDENWALD LITH BALTO

YOUNG ORANGE TREE HEALTHY AND DISEASED

## PLATE VIII.

ORANGE RUST.

(After Hubbard.)

## PLATE IX.

KATYDIDS ON ORANGE.

(After Comstock.)

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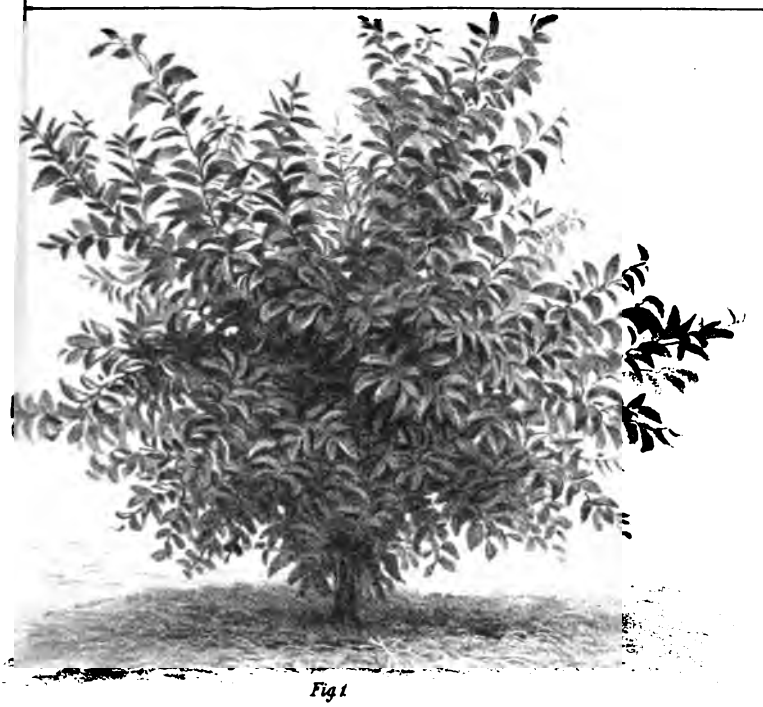
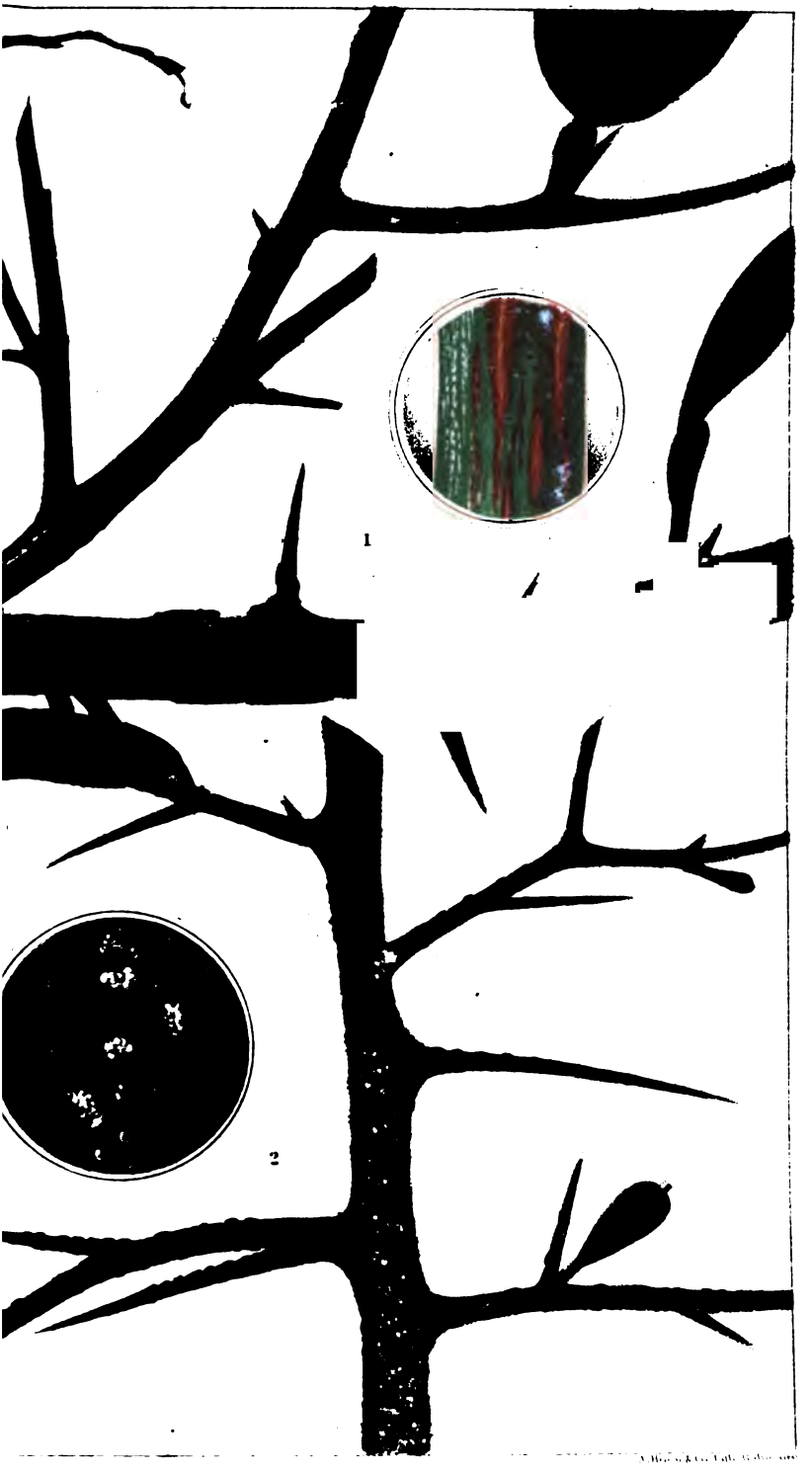


Fig 1

Fig 2

ISAAC FRIEDENWALD LITH BALTO

YOUNG ORANGE TREE HEALTHY AND DISEASED




"DIE BACK" OF THE ORANGE.

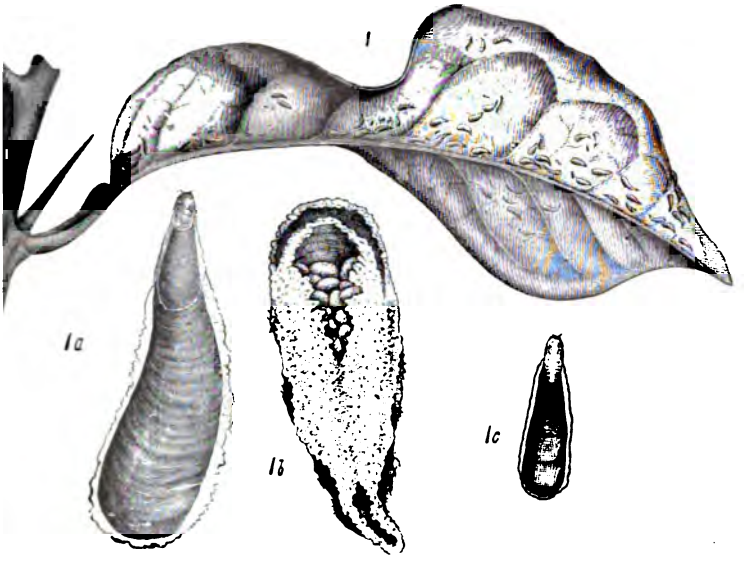



Fig. 1.

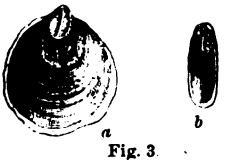



Fig. 3.

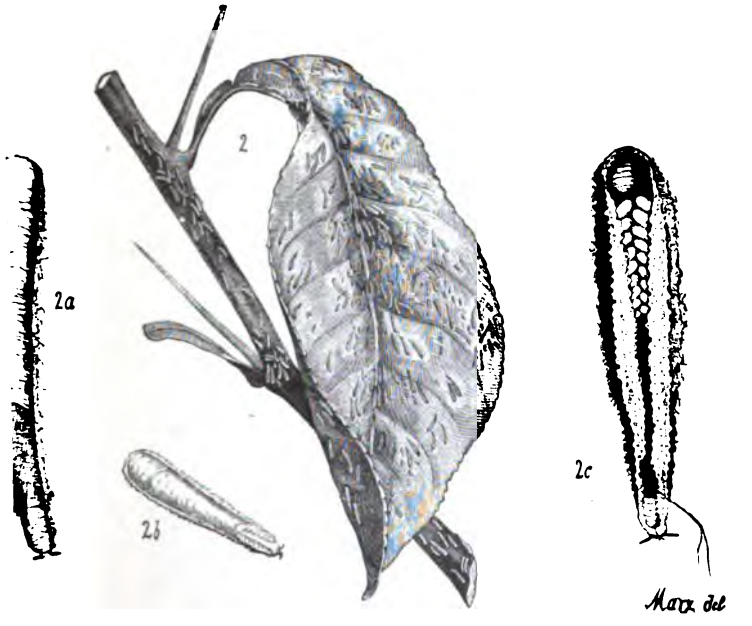



Fig. 2.

THE COMMON ARMORED SCALES OF THE ORANGE.

TWIGS OF ORANGE *INFECTED WITH LONG SCALE*

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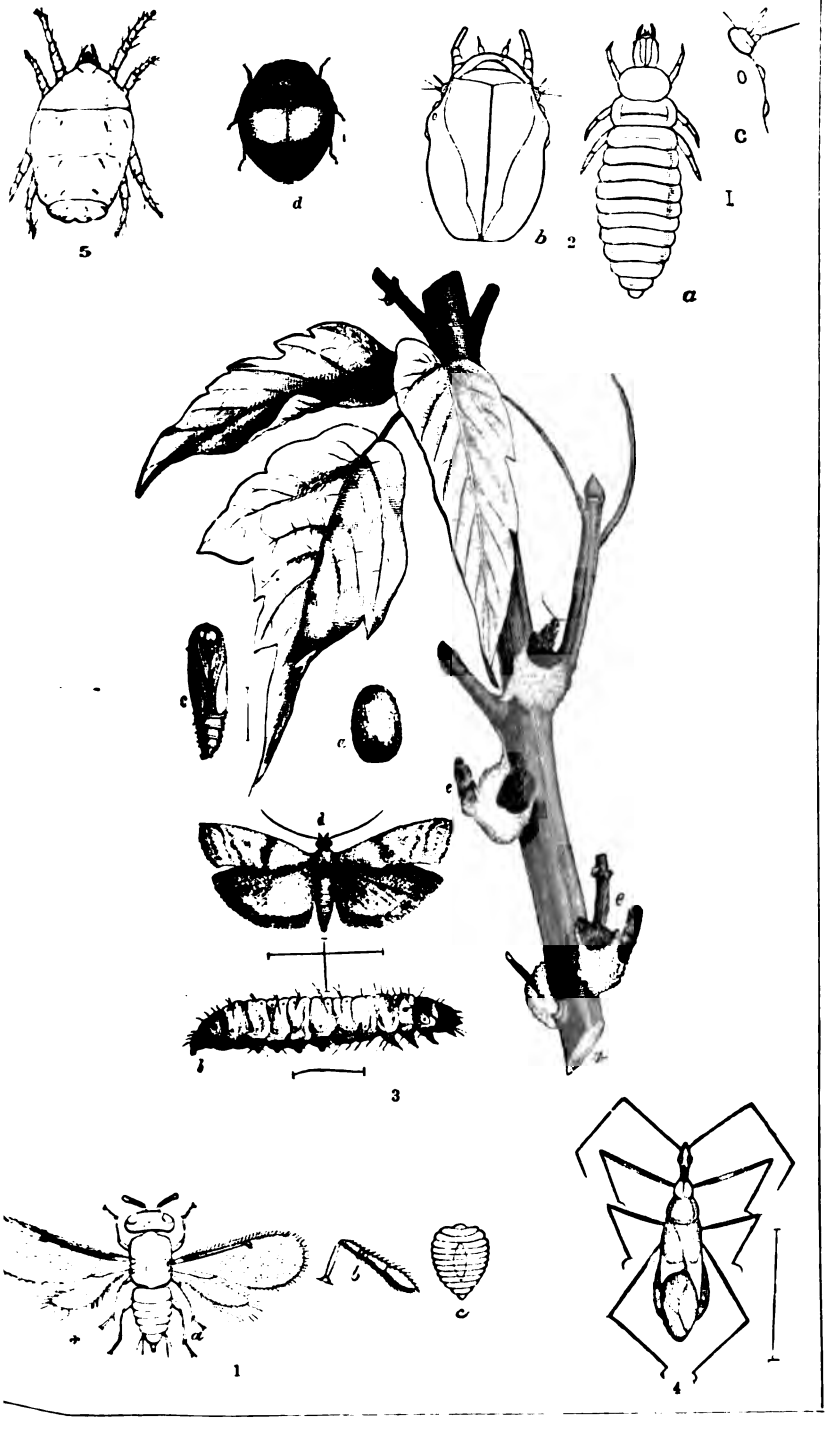
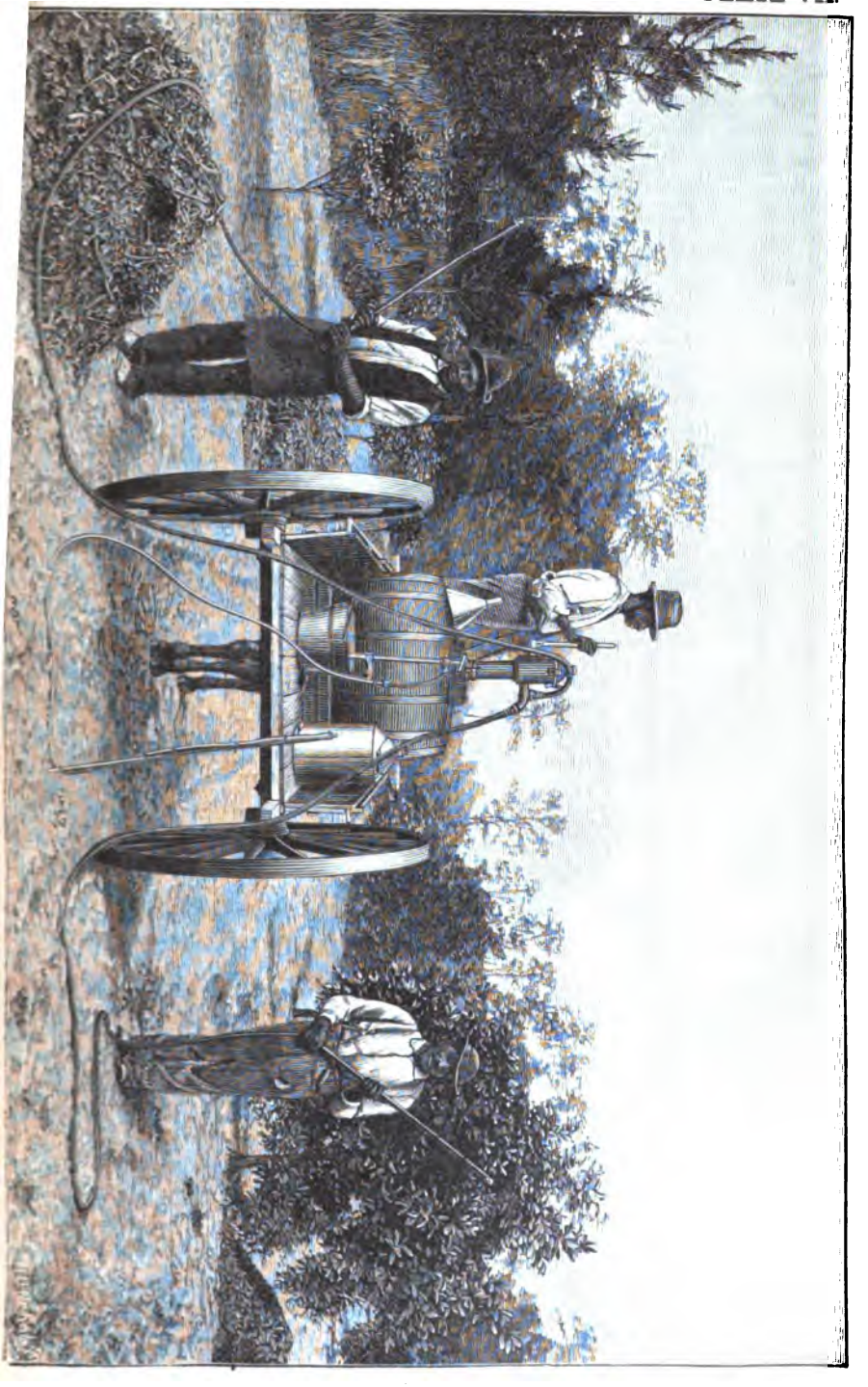
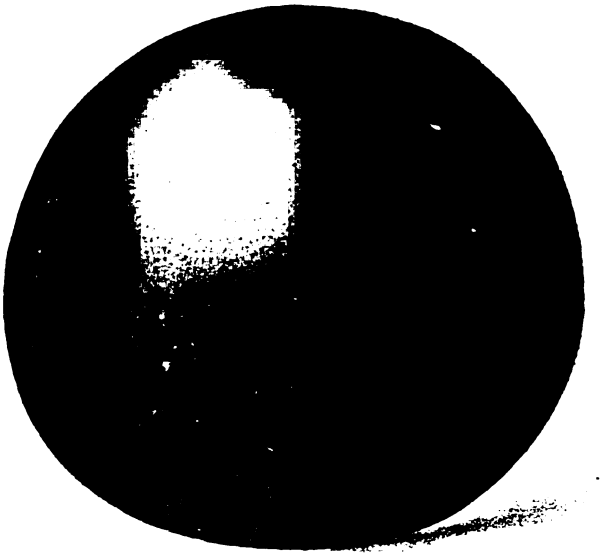
"CHAFF *SCALE*" *OF THE* ORANGE



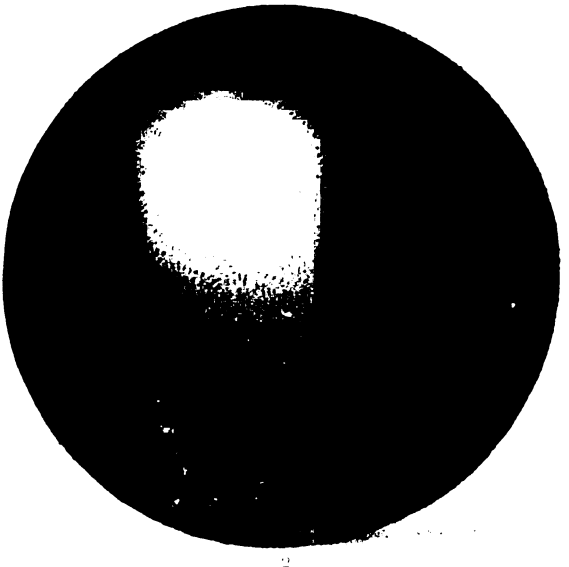

ENEMIES OF BARK-LICE.



APPARATUS FOR SPRAYING ORANGE TREES.
(From a photograph taken in the field.)



1



2

RUST OF THE ORANGE.

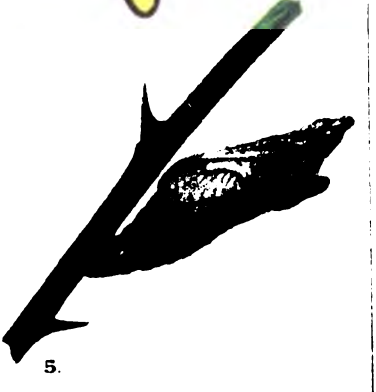
KATYDIDS ON ORANGE.

3.

4.

1.

2.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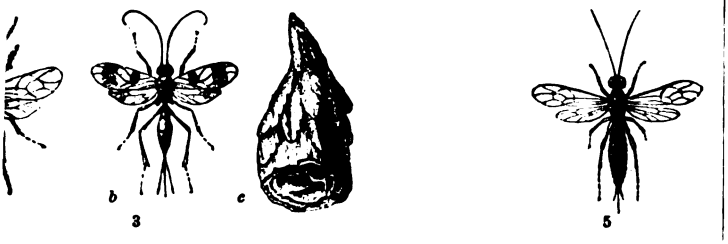
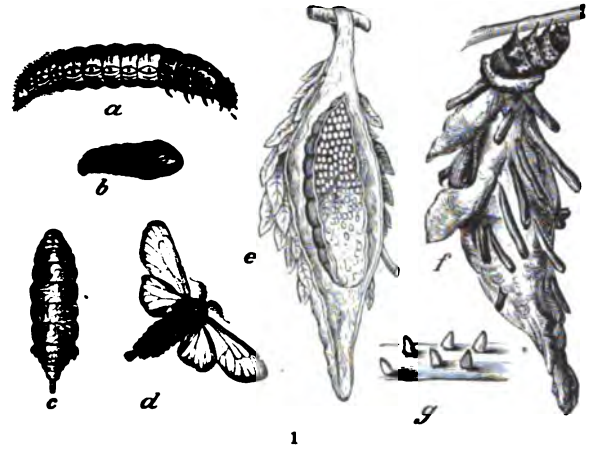
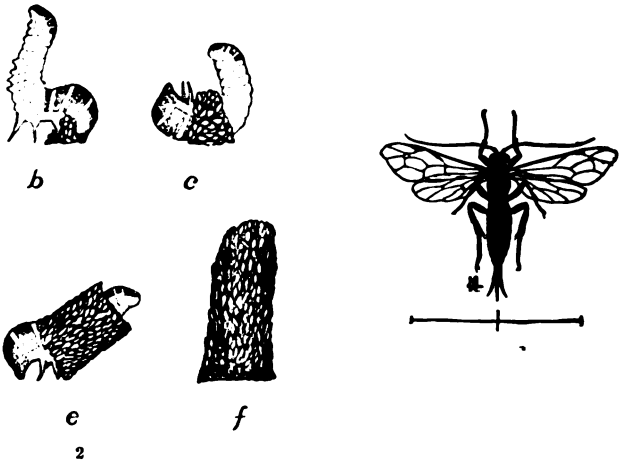
THE "ORANGE DOG".

ISCELLANEOUS *ORANGE* INSECTS.

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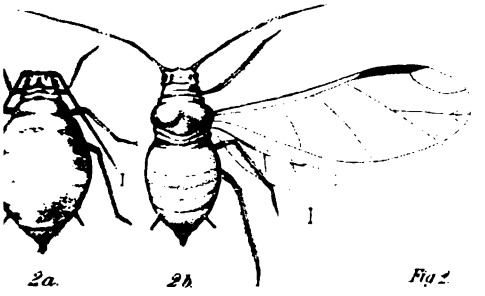

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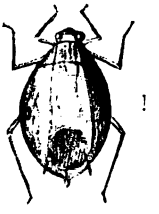

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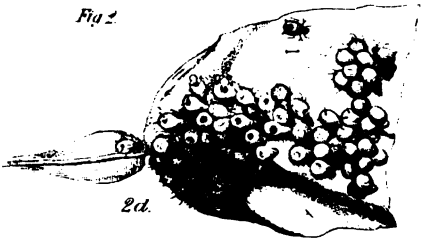

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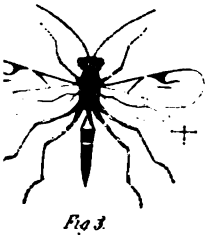

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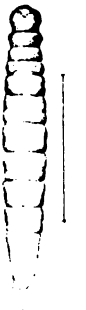

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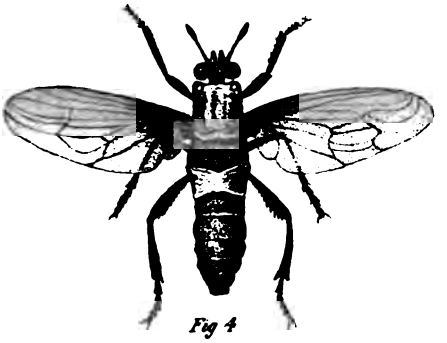

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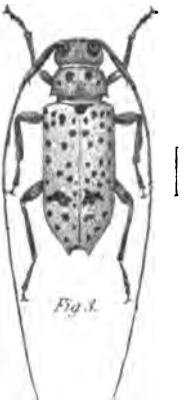

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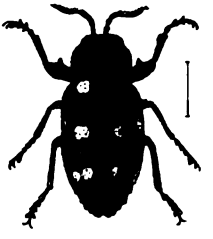

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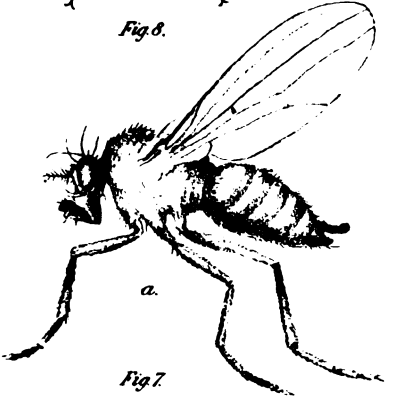

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a. Fig 2

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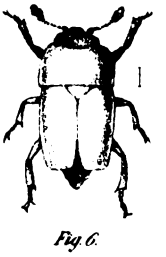

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blications of the United States Geological Survey are issued in accordance with the statute March 3, 1879, which declares that—

ublications of the Geological Survey shall consist of the annual report of operations, geo- d economic maps illustrating the resources and classifications of the lands, and reports upon ıd economic geology and paleontology. The annual report of operations of the Geological ıall accompany the annual report of the Secretary of the Interior. All special memoirs and f said Survey shall be issued in uniform quarto series if deemed necessary by the Director, wise in ordinary octavos. Three thousand copies of each shall be published for scientific s and for sale at the price of publication; and all literary and cartographic materials received ıge shall be the property of the United States and form a part of the library of the organ- And the money resulting from the sale of such publications shall be covered into the Treas- e United States."

y 7, 1882, the following joint resolution, referring to all Government publications, was passed ess:

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these general laws it will be seen that none of the Survey publications are furnished to it for ıs distribution. The 3,000 copies of the Annual Report are distributed through the document- Congress. The 1,900 copies of each of the publications are distributed to the officers of the re and executive departments, and to stated depositories throughout the United States.

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## ANNUAL REPORTS.

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t Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map. A ary report describing plan of organization and publications.

port of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. . lv, 568 pp. 61 pl., 1 map.

hird Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. . xviii, 564 pp. 67 pl. and maps.

ırth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. . xii, 473 pp. 85 pl. and maps.

fth Annual Report is in press.

## MONOGRAPHS.

# ADVERTISEMENT.

IX. Brachiopoda and Lamelli branchiata of the Green Marls and Clays of New Jersey, by R. P. Whitfield.

Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. In preparation.

Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague. In preparation.

Lake Bonneville, by G. K. Gilbert. In preparation.

Dinocerata: A Monograph on an Extinct Order of Ungulates, by Prof. O. C. Marsh. In preparation.

Sauropoda, by Prof. O. C. Marsh. In preparation.

Stegosauria, by Prof. O. C. Marsh. In preparation.

Of these Monographs, Nos. II, III, IV, V, VI, and VII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by C. E. Dutton, Capt. U. S. A. 1882. 4°. 264 pp. 42 pl. and atlas of 26 double sheets folio. Price, $10.12.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price, $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 8 pl. Price, $1.50.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. 1883. 4°. xiv, 464 pp. 29 pl. Price, $—.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by William M. Fontaine. 1883. 4°. XIX, 144 pp. 54 l., 54 pl. Price, $—.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. XII, 200 pp. 15 pl. Price, $—.

Nos. VIII and IX are in press and will soon appear. The others, to which numbers are not assigned, are in preparation.

## BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper, and be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1, 2, 3, 4, 5, 6, 7, and 8 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 40 pp. 2 pl. Price, 10 cents.

2. Gold and Silver Conversion Tables, giving the Coining Value of Troy Ounces of Fine Metal, &c., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price, 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the Meridian of 76° 20′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price, 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price, 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price, 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price, 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South) 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price, 10 cents.

## STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, is contemplated. Of that series the first has been published, viz: Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price, 50 cents.

Correspondence relating to the publications of the Survey, and all remittances, which must be by postal note or money-order, should be addressed to the

DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY,
*Washington, D. C.*

WASHINGTON, D. C., *August* 30, 1884.

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UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL DIRECTOR

# MAPOTECA GEOLOGICA AMERICANA

## A CATALOGUE

OF

## GEOLOGICAL MAPS

OF

## AMERICA (NORTH AND SOUTH)

1752–1881

IN GEOGRAPHIC AND CHRONOLOGIC ORDER

BY

JULES MARCOU and JOHN BELKNAP MARCOU

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

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## CONTRACTIONS USED IN REFERENCES.

Where not otherwise stated, the geological maps are in colors, and the works containing them are in octavo.

When a map contains a part of countries belonging to other great geographical divisions, as adopted in this catalogue, it is always placed in the division embracing most of its area. For instance, the "Carte géologique des bords du Lac Champlain," embracing parts of Vermont, New York, and Canada, is put in New England, because it covers more of Vermont than it does of Canada or New York, but in the index of places New York and Canada are referred to as countries contained in the map.

In the chronological order, when no question of priority is involved, the maps of the same year are classified in the alphabetical order of their authors.

*Amer. Journ. Silliman.*—The American Journal of Science and Arts. New Haven, Conn.

*Ann. New York Acad. Sci.*—Annals of the New York Academy of Science. New York.

*Bull. Soc. Géol. France.*—Bulletin de la Société Géologique de France. Paris.

*Geol. Surv. Canada.*—Geological Survey of Canada.

*2d Geol. Surv. Pennsylvania.*—Second Geological Survey of Pennsylvania.

*Journ. Acad. Nat. Sciences.*—Journal of the Academy of Natural Sciences of Philadelphia. 4to. Philadelphia.

*Journ. Geol. Soc. London.*—The Quarterly Journal of the Geological Society of London.

*Mem. Mus. Comp. Zoöl. at Cambridge.*—Memoirs of the Museum of Comparative Zoölogy at Cambridge, Mass.

*Proc. Acad. Nat. Sciences.*—Proceedings of the Academy of Natural Sciences of Philadelphia.

*Proc. Amer. Phil. Soc.*—Proceedings of the American Philosophical Society held at Philadelphia for promoting Useful Knowledge.

*Trans. Amer. Phil. Soc.*—Transactions of the American Philosophical Society held at Philadelphia for promoting Useful Knowledge. 4to.

*Trans. Amer. Inst. Mining Engrs.*—Transactions of the American Institute of Mining Engineers. Easton, Pa.

*Trans. Lit. and Hist. Soc. Quebec.*—Transactions of the Literary and Historical Society of Quebec.

*Trans. North of England Inst. Mining Engrs.*—Transactions of the North of England Institute of Mining and Mechanical Engineers. Newcastle-upon-Tyne.

*U. S. Geol. and Geogr. Surv. Territories.*—United States Geological and Geographical Survey of the Territories. Washington.

*Zeitsch. Deut. Geol. Gesells.*—Zeitschrift der Deutschen Geologischen Gesellschaft. Berlin.

# INTRODUCTION.

The late Uricoechea, of Bogota, when he offered me a copy of his "Mapoteca Colombiana[1]" said: "I hope that the study of this catalogue may lead you to undertake another one on the geological maps of America. Our views on the ancient geography of the world. discovered by Columbus, and on the aboriginal or Indian origin of the name America,[2] are so harmonious, and geology being the history of the earth, a catalogue of all the geological maps published on America will be an important chapter in the history of Columbian cartography."

I have now endeavored to fulfill the wish of my friend. Taking for a model his "Mapoteca Colombiana," a work which is out of print and has become rare, I have united in chronologic and geographic order all the maps relating to American geology known to me.

In general, catalogues of maps are not numerous. Those of geological maps only are very rare. I know of only one purporting to comprise the maps of all the world; it is the "Geognostische Karten unseres Jahrhunderts." Zusammengestellt von Bernhard Cotta, Freiberg (Saxony), 1850. 8vo of only 60 pages. The author, although he has placed in it maps pertaining purely to physical geography, such as the geographical distribution of volcanoes, has only succeeded in enumerating 571 geognostical maps. America is placed in the last division "VI. Ausser-Europa," and its geological maps are united with those of Asia, Africa, Australia, and Oceania. All these large geographical divisions outside of Europe have but 53 numbers, of which 30 belong to maps on the geology of America; and several of the numbers indicate memoirs without geological maps properly so called, and some even without any kind of a map; for instance, No. 525, Finch "Karte de Gegend von Boston," in Silliman's Journal of Science, Vol. VIII, 1824, which does not exist, and is merely an error of the compiler.

Besides the catalogue of Cotta, the only list of geological maps of America is the "list of general geological maps relating to North America" in the "Geology of North America," by Jules Marcou, Chapter X, p. 122. 4to. Zurich, 1858. The author enumerates 23 general geological maps, in chronologic order, each comprising at least two States.

Two of the geological surveys of the United States, Dr. Hayden's and

[1] "Mapoteca Colombiana, Coleccion de los Titulos de Todos los Mapas, Planos, Vistas, etc., relativos a la America española, Brasil e Islas adyacentes." 8vo. Londres, 1860.

[2] "Origin of the name America," by Jules Marcou. Atlantic Monthly, March, 1875.

the one directed by Captain Wheeler, have given catalogues of publications, reports, and maps, in which are lists of a part of the geographical maps published by these surveys. The geological survey of Canada also has published a list of its maps.

For the last forty years especially, geological maps on America have accumulated in large numbers, thanks to the geological surveys instituted either by the general governments or by States and Provinces. The United States, Canada, Mexico, Chili, and a large number of States and Provinces have rivaled each other in this field of science. Memoir after memoir, map after map, has been produced to show the geological structure of countries which yesterday were unknown, but to-day are marshaled in the scientific movement which carries forward in its progress all the nations of the world.

Geology, properly so called, dates only from this century; in the preceding one a few maps, rather mineralogical, than geological, appeared. Such are the maps of L. Coulon in 1664; of Guettard in 1746; of Monnet on France in 1780; of Guettard on North America in 1752; of von Charpentier the elder on Saxony in 1778; of Becker on the Grand Duchy of Nassau in 1778; of von Buch on Silesia in 1797; of Hein on the Thüringen Waldes in 1799; of Christopher Packe on East Kent in 1743; of R. Frazer and J. Billingsley on Devonshire and Somerset in 1794; of Maton on the Western Counties (England) in 1797.

The first geological map is due to the abbé L. Coulon, Paris, 1664. It appeared in a little volume entitled, "Les Rivières de France," a very rare work, of which but very few copies exist in the libraries of Paris. In 1683 Martin Lister read a paper before the Royal Society of England entitled, "An ingenious proposal for a new sort of maps of countries; together with tables of sands and clays, such as are chiefly found in the north part of England"; in Phil. Trans., Vol. XIV, p. 739. London, 1684. But it was only a project, which Lister did not carry into execution. The first geological map published in England is dated 1743, almost a century after Coulon's little geological map of France; its title is, "A new Philosophico-chorographical chart of East Kent, invented and delineated by Christopher Packe, M. D." Scale rather more than an inch and a half to the mile, comprising a circle of about 32 miles around Canterbury.

To the celebrated Abraham Gottlob Werner is due, in great part, the coloring of geological maps; for before him several older German mineralogists had used an analogous process. Werner greatly improved not only the classification but also the plan of coloring, and proposed a method "of representing the several formations in distinct, but sober hues, and marking the superior rock by a narrow band of deeper color, along the lines of its contact with the subjacent one" (Dr. Fitton's Notes on the History of English Geology, London, 1833). This method of coloring was employed chiefly in Germany, in German Switzerland, a little in Scandinavia, and in England; never in France or in America.

As early as 1810 Cuvier and Brongniart, in their celebrated "*Carte Géognostique des environs de Paris*," used even tints without a "band of deeper color along the line of contact."

William Maclure, who, though a pupil of Werner, was also well acquainted with the French geological school, colored his first geological map of the United States in 1809 with even tints. Since 1832 the German school as well as the English has adopted even tints.

Curiously enough the first edition of his geological map of the United States appeared without the name of Maclure, and is sometimes credited to Samuel G. Lewis, the draftsman who compiled the geographical map on which Maclure put his geological classification and colors. This mistake and the use of a drawing by Lewis were due "to the absence (from America) of the author of "*Observations on the Geology of the United States, explanatory of a Geological Map*," read before the American Philosophical Society at Philadelphia January 20, 1809.

From 1809 to 1842 all the geological maps published on America were executed in a manner which leaves much to be desired in respect to coloring, and still more in regard to the classification of the rocks. It is only after the appearance of the "*Geological Map of the State of New York*" in 1842 that maps really possess great interest either from the value of their classifications or from the mechanical execution.

The same year a geological map of great importance, both on account of the difficulties presented by the region explored, the most elevated of the Andes, and of its central position in South America, was published by Alcide d'Orbigny under the title "*Carte Géologique de la République de Bolivia*." From that time nearly all the great geological and paleontological horizons of the New World were accepted as established, though geologists hesitated for a few years about the acceptance of the existence of several systems of stratified rocks, and also about the identification of certain paleontological horizons.

Between 1842 and 1862 there appeared a great number of geological maps of regions limited either to single countries or parts of countries, or even to a single county, or a portion of one, as well as several attempts at general maps of North America, of South America, and even of both Americas together. However, all of them have an essentially temporary character, and are geological reconnaissances. Nothing truly studied in detail and with care had then appeared. This was owing to several causes. First the total absence of good topographical maps, and often even the absence of any kind of a map, geologists being obliged to make them themselves, in order to draw and color the systems of rocks. Then the vast surfaces to be studied, the great distances to be traversed before reaching the ground to be explored, the difficult and primitive modes of transportation before the construction of lines of railroads, the wilderness and the deserts of most central continental regions, and finally the unhealthy climate of the tropics and the banks of the great rivers. All these obstacles have conspired to render

researches difficult, and to give them the character of simple geological reconnaissances. In new countries, the first thing is to obtain a sketch approximating to the truth, and afterwards to proceed to detailed studies.

It was during this period, from 1842 to 1862, that the system of coloring geological maps underwent a complete change. Till then everything was done by hand, and seldom with care. Maps were colored rapidly, and tints varied not only from one copy to another, but also on the same map, some parts being a shade lighter or darker than others; besides, traces left by the brushes added to the imperfection of the work. Finally, the overlapping of one color on another at the limits of the different systems delineated on the map often took such alarming proportions that it was impossible to tell to what formation considerable belts of country were referred. It was only by the skill derived from practice that the defects of hand-coloring were much diminished. It may be said that the geological survey of the United Kingdom of Great Britain and Ireland attained the highest possibilities of the method by forming a special corps of colorists who did nothing else for years, and by being very strict in the acceptance of the colored sheets, every one that had an apparent defect being invariably rejected.

As early as 1841 attempts at colored printing had been tried by Major Le Blanc, chief of the office of topographical engineers at Paris. This was his method: He used a sheet of tin-foil similar to that employed in the manufacture of looking-glasses, on which he fixed a proof of the map or geological section which he wished to reproduce. They were then cut out simultaneously, which gave a tin pattern of the formation. Then the color was placed on it by means of brushes prepared for the "lucidonique" method of painting, and the maps were printed under a press. This method from the first secured promptness, exactness, and cheapness of coloring.

The first sheet colored by this system of "poncis découpés," with mechanical impressions, represents "*Coupes géologiques et topographiques des environs de Paris*," made for the use of the military engineers, in the location of the fortifications of Paris, created under Louis Philippe. Shortly afterward Messrs. Le Blanc and Raulin undertook to color by this system a geological map in one sheet, "grand aigle," which appeared in 1843 with the title "*Carte géognostique du Plateau tertiaire Parisien*," by Victor Raulin. Then Major Le Blanc undertook the impression in colors of the "*Carte géologique du globe terrestre*," by Boué, in one sheet. It is dated Paris, 1845, and bears this note: "Sous les auspices et la direction de la Société géologique de France par les soins et procédés de M. Le Blanc, vice-secrétaire." The execution took longer than was expected, and the map was not given to the public until the spring of 1846. The results obtained were quite defective, both as to the character of the colors, and exactness in outline, several colors either failing to meet or overlapping each other. However, these first

attempts were quite encouraging; especially as the cost was much less than by the hand process.

In April, 1846, I offered to the *Société géologique de France* for publication in its memoirs, my work entitled "*Recherches géologiques sur le Jura Salinois*," with a geological map of the country round Salins, scale 1:80,000, taken from the "*Carte dite d'État-Major.*" Having been accepted by the committee on publications, Major Le Blanc offered to try his process of mechanical coloring, his offer was accepted, and my geological map of the Jura Salinois was the first printed in color that appeared in the publications of the *Société géologique de France.* The execution occupied 1846 and 1847, and the memoir, with the map, appeared in January, 1848. It has the same defects as the map of Boué, only they are more prominent because of the large scale.

The multiplication of geological maps, and the difficulties of satisfactory and rapid coloration by hand, rendered the invention of improved methods more and more important. Dufrénoy and Élie de Beaumont, after the publication of their great geological map of France in six sheets, began the trial of lithographic coloring at the Royal press of Paris, on a map called: "*Tableau d'assemblage des six feuilles de la carte géologique de France,*" in a single sheet, scale of 1:2,000,000. Previously this "*Tableau d'assemblage,*" colored by hand, had been placed at the end of the first volume, 4to, of the "*Explication de la carte géologique de France,*" 1841. The copies of this volume distributed from 1811 to 1853 all contain this map colored by hand. But after 1853, or at the beginning of 1854, there appeared at the end of the volume which still bears the date: "*Paris, Imprimerie Royale, MDCCCXLI,*" the map of the "*Tableau d'assemblage,*" with the inscription to the right at the bottom of the map; "*Lithographie de l'Imprimerie Imperiale.*" This chromolithographic map of the imperial press was a success; the colors are brilliant and uniform and do not overlap each other. All the copies of Volume I of the "*Explication de la carte géologique de France,*" of Dufrénoy and Élie de Beaumont, since distributed, have this chromolithographic map.

Before we leave the "Imprimerie Nationale de France" let us mention the beautiful geological maps that have been made there, and whose execution has nowhere been surpassed, not even in these last years of progress of chromolithography. First, the "*Carte géologique de la Belgique et des contrées voisines*" by André Dumont, one sheet, 1855, a real masterpiece of coloring, especially if we consider the numerous superpositions of simple colors, which determine the greater part of the *forty-two* different tints of the *tabular view* of the map. The "*Carte géologique de l'Europe,*" also by André Dumont, in four sheets, 1855–1857, is another fine example of coloring, far superior to the one made at the same time at Edinburgh by Keith Johnston for Sir Roderick Murchison's and Nicol's "*Geological Map of Europe*" in four sheets, 1856. Finally, the maps of the *État-Major*, scale of 1 : 80,000, used by the service of the

"*Carte géologique détaillée de la France*" have been colored by chromolithography since 1877, instead of coloring by hand employed up to that time.

Many improvements have been added to the first methods employed in 1854. The most important consists "in placing on metal by putting in relief the sheets of a map, and in operating the impression in colors under the *typographical presses*." From the Imperial press, chromolithography soon extended to private industry. In Paris, Messrs. Lemercier & Cie. printed chromolithographically, in May, 1855, the "*Carte géologique des États-Unis et des Provinces anglaises de l'Amérique du Nord*," by Jules Marcou, and in August the "*Carte géologique du Canada*," by W. E. Logan.

In Germany analogous attempts, by means of lithographical impressions in oil colors were made at the same time. In 1842 two chromolithographic geological maps appeared, namely: "*Carte géognostique du Taurus et de ses environs*," in folio, by M. J. Russegger, published at Stuttgart; and the geological wall map of Germany by Woelter, published at Eslingen (Wurtemberg). Then in 1845 another chromolithographical map by Major Heinrich Bach, representing the geology of Wurtemberg, appeared also at Stuttgart. All these maps, as well as those that followed, show great defects, both on account of lack of clearness in the colors, all being too dark, and bad registration.

Chromolithographic geological maps appeared in Berlin and in Vienna in 1851, in the "*Zeitschrift der deutschen geologischen Gesellschaft*" and in the "*Jahrbuch der k. k. geol. Reichsanstalt*." In 1853 in Switzerland, at Winterthur, J. Wurster & Cie. chromolithographed the "*Carte géologique de la Suisse*," by B. Studer and A. Escher de la Linth. Several of the shades in this map were put on by hand, so that it was a sort of hybrid between the two systems.

In 1854, Justus Perthes, in Gotha, published a very well executed chromolithographical map, "*Geognostische Karte des Thüringer Waldes*," by H. Credner, lithographed by C. Hellfarth; and, in the same year, a map also very well executed, "*Geognostische Karte von Kurhessen*, by A. Schwarzenberg and H. Reusse, lithographed by C. Kegel, of Cassel. The last one, especially, is a success, the coloring being but little inferior to that of the geological map of France of 1853.

In America the systems of color-printing replaced but slowly the hand processes. The late A. Sonrel, the well-known draftsman of Louis Agassiz, tried a system analogous to that of Major Le Blanc, and in 1853 he successfully executed a little geological map, which appeared in a public document of the Commonwealth of Massachusetts, entitled: "*Report on certain points in the geology of Massachusetts*," by Edward Hitchcock. The map has no title, date, or place of publication, and no name of the engraver or printer. It embraces the coal field of Bristol County and of Rhode Island.

Sonrel's system consisted in cutting slips of card-board to correspond exactly with each color. These were then accurately glued to a wooden base and color applied to them by a printer's cylinder. An impression from them was then taken by a lithographic press.

In 1855 J. H. Colton & Co., of New York, engraved and printed in colors the "*Geological map of the State of Alabama*," accompanying the "Second biennial report of the geology of Alabama", which did not appear until in 1858, owing to the death of M. Tuomey, State geologist. Messrs. Colton & Co. also engraved and printed in colors the numerous maps of Oscar M. Lieber, geologist of South Carolina from 1856 to 1860.

About 1868, thanks to the celebrated cartographical house of Julius Bien, of New York, chromolithography at last came into general use in the United States for coloring geological maps. Several of the maps made by Bien are irreproachably executed and compare favorably with those made at Vienna, Munich, Berlin, Paris, London, and Bruxelles. During the civil war in the United States there was a great falling off in the publication of geological maps on that portion of America. But shortly after its termination, a new impulse of unprecedented strength, caused not only the resumption of interrupted works, but also the birth of many new ones. The Federal Government took the lead by causing the exploration of a part of the immense territories of the West. Excellent results have already been obtained, and the important geological atlases published during the last few years under the direction of Messrs. Clarence King, F. V. Hayden, J. W. Powell, and George M. Wheeler, are an honor to the Government of the United States, and to the geologists who constructed them. The States of Michigan, Wisconsin, Ohio, Missouri, New Hampshire, and Pennsylvania have also published large geological atlases, well executed in chromolithography. The Dominion of Canada has continued with improved success its publication of geological maps of the British Possessions in North America. Finally, British Guiana, Brazil, the Argentine Republic, and Chili have undertaken geological surveys, which, in the last twenty years, have largely augmented our knowledge of the geology of South America. The geological map of Chili, in thirteen sheets, by Pissis, published chromolithographically in Paris, compares favorably with any atlas published in North America.

Geological mapping in this country was greatly improved between 1862 and 1881, without, however, attaining that degree of perfection reached by the old and very detailed geological surveys of England, France, Switzerland, Belgium, Austria, Prussia, or Scandinavia. Although the latest geological publications on America are very superior to those which preceded them, there has not been executed a geological survey of any large area that is really final, or that leaves but little to be corrected in the future. With limited exceptions, all are geological reconnaissances, which still demand many years of work to transform them into definite and completed studies. However,

what exists already is enormous in importance and in extent, when we consider the immense stretch of land explored, from the Arctic to the Antarctic regions.

In judging the results obtained by the efforts of, after all, a rather small band of field geologists, we must not lose sight of the fact that America occupies a hemisphere, and that, compared with the Old World, the New is better known geologically, and has far less blank space on a general geological map than Asia, Africa, or Australia.

In looking over this catalogue, one will often be struck by certain peculiarities in the maps cited. Some are anonymous, others have no titles, some have no date, others have no scale, or a scale which has to be figured out to understand it exactly; in this case we have not cited the scale. Often no place of publication is given; even whole geological atlases are without such designation. Very often the date on the map does not correspond to the date of the book or memoir which describes it; in which case I have mentioned both dates, first that of the map and then that of the book. Finally, I have had to eliminate a certain number of maps called geological in their titles, which really have nothing geological about them. I have also neglected citing very small maps reduced from larger ones, which authors of elementary books have inserted in their texts in black engravings or wood cuts; for they are all reproductions—often very poor ones—of maps made by original observers, whose names are neither on these maps nor in the texts. They are merely for the use of the general public and student, and are without value in the history of science. Unfortunately no kind of publication offers greater temptations for appropriating the work of others without proper credit, than a geological map. It is offered in excuse that the knowledge belongs to the public, but geologists who respect the property of their fellow-workers, and who know that often the only recompense of very difficult work, without any pecuniary remuneration whatever, is the reputation derived from it, do not fail to cite the name or the names of the first explorers or investigators, either on the maps or in the explanatory text, or in both. Too often this simple rule of justice is violated, and numerous acts of real scientific piracy exist in geological cartography. The persons most often guilty of it are mining engineers, geographers, and travelers. Thus, one often finds in the narrative of a voyage, or in mining magazines, large geological maps, well colored and tolerably exact, with the name of an author wholly unknown in geology. If these maps are compared with those of the geologists who have made a study of the countries represented, it is surprising to find that they are exact copies, so exact indeed that they repeat faults known only to their authors. In this case the evil is not great, for every one rectifies the error and places the name of the true author in the place of that of the unscrupulous compiler.

But it is not the same thing when the author of the compilation is a known geologist. It then becomes very difficult to know what really

belongs to the geological predecessors and pioneers whose works have been appropriated without citing them. But very few scientists are capable of re-establishing the truth, and often when they know it they dislike to make it public and expose the piracy of a fellow scientist. The only remedy for this evil is the reputation which each one possesses in science. He who respects and cites all the maps and works of his predecessors is sure of having the reputation of an honest observer, even when his works are disagreeable to some of his co-laborers. While he who appropriates right and left the works of others is soon known and cited as an unscrupulous compiler, and of doubtful standing as a geologist.

Almost all the geological maps cited in this "Mapoteca" are in my library—especially all the pioneer maps, a few of which are very rare, and command a high price.

The public libraries of Cambridge and of Boston have allowed us to complete what we lacked. There is only a very small number of maps, hardly a dozen, that I have not seen, and in this case I have always added the word *unseen*. Some of these even I have seen in European libraries nearly thirty years ago, at a time when I did not think of making a catalogue.

Notwithstanding all the care and diligence with which I have searched for years, a number of geological maps of America must have escaped me, as happens in all catalogues, but I believe that nothing important will be found wanting.

This list stops with the year 1881, inclusive.

JULES MARCOU.

CAMBRIDGE, MASS., *September*, 1882.

## IRICA IN GENERAL, COMPRISING BOTH NORTH AND SOUTH AMERICA.

1.

**ıué (Ami). Carte géologique du globe terrestre. Paris, 1845.**

In one sheet only. America is colored geologically, with the data then ıown, which covered only about one-twelfth of the whole continent. The ıt is mere conjecture. It is a bold attempt at generalization with a small sis of facts. It was republished by Edward Hitchcock, without the name Boué, under the title of "Outline of the geology of the globe." 1853. :ompanying "Outline of the geology of the globe, and the United States in ırticular", by Edward Hitchcock. Boston, 1854.

An English edition, by A. K. Johnston, appeared in 1855 in his Physical las of natural phenomena, Plate I, under the title "The geological struct- e of the globe according to Ami Boué." Edinburgh, 1855.

A German edition, in Berghaus Physikalischer Atlas, appeared in 1856? ate 9, under the title "Geologische Erdkarte nach Ami Boué und K. John ɔn von Traugott Bromme." Stuttgart, 1856?

2.

**ıylor (R. C.). Chart showing the position of the coal fields on ıe surface of the globe.**

Accompanying "Statistics of coal." Philadelphia, 1848.

A second edition was published by Haldeman.

3.

**h (Leopold von). Die Verbreitung und die Greuzen der ide-Bildungen. Mercator projection.**

ompanying "Betrachtungen über die Verbreitung und die Greuzen der le-Bildungen"; Verhandlungen des naturhistorischen vereins der Preuss- ı Rheinlande und Westphalens. Bonn, 1849.

ry small map, showing, in black etching, the geographical distribution cretaceous rocks in North and South America. Also issued separately.

4.

**ock (Edward). Outline of the geology of the globe.**

panying "Outline of the geology of the globe, and the United States ular." Boston, 1854.

ıué (Ami), 1843—No. 1.

5.

**mi). The geological structure of the globe according to ıé.**

nying "Physical atlas of natural phenomena", by A. K. Johnston, dinburgh, 1855.

(Ami), 1843—No. 1.

6.

**1856—Boué** (Ami) and **Johnston** (K.). Geologische Erdkarte nach Ami Boué und K. Johnston von Traugott Bromme.

Accompanying "Berghaus Physikalischer Atlas," Plate IX. Stuttgart, 1856?

See **Boué** (Ami), 1843—No. 1.

7.

**1860—Marcou** (Jules). Geological map of the world Carte géologique de la terre. Scale 1: 23,000,000. Winterthur (Switzerland), 1861.

In eight sheets. In this map localities of which the geology was unknown were left blank. Reductions of it appeared in Élisée Reclus "La Terre," Vol. I, Les continents. "Carte géologique du Monde, d'après Jules Marcou." Plate II, p. 30. Paris, 1868. Of this there are four editions. By an oversight of the translator, Mr. Henry Woodward, the author's name was omitted in the English editions entitled "The Earth," by Élisée Reclus.

Prof. Oscar Fraas reproduced a reduction of the first edition of this map in his "Vor der Sündfluth," Stuttgart, 1865, with the author's name omitted; in the subsequent editions of his work he repaired his forgetfulness. In 1872 a reduction of the first edition, in one sheet, appeared in Vienna, in the "Physikalische Karten," published by Artaria & Co. under the title "Geologische Uebersichtskarten der Erde nach Marcou."

8.

**1865—Marcou** (Jules). Geological map of the world (reduction of).

Accompanying "Vor der Sündfluth," by Oscar Fraas. Stuttgart, 1865.

See **Marcou** (Jules), 1860—No. 7.

9.

**1867—Simonin** (Louis). Carte des terrains houillers du globe et de l'exportation du charbon anglais d'après Taylor, Marcou et les documents officiels.

Accompanying "La vie souterraine, ou les mines et les mineurs." Carte I, p. 32. Paris, 1867.

It is a reduction of R. C. Taylor's chart, with additions from the first edition of Marcou's Geological map of the world.

10.

**1868—Marcou** (Jules). Carte géologique du monde d'après Jules Marcou.

Accompanying "La Terre," by Élisée Reclus, Vol. I, Plate II, p. 30. Paris, 1868.

See **Marcou** (Jules), 1860—No. 7.

11.

**1870—Marcou** (Jules). Carte géologique du monde.

Accompanying "La Terre," by Élisée Reclus, 2d edition, Plate II. Paris, 1870.

See **Marcou** (Jules), 1860—No. 7.

12.

**1871—Marcou** (Jules). Geological map of the world.

Accompanying "The Earth," by Élisée Reclus, Plate II. London, 1871.

The name of Jules Marcou has been dropped, not by the translator, Mr. Henry Woodward, but by the publisher.

See **Marcou** (Jules), 1860—No. 7.

13.

**1872—Marcou** (Jules). Geologische Uebersichtskarten der Erde, nach Marcou.

Accompanying "Physikalische Karten," published by Artaria & Co. Vienna, 1872.

See **Marcou** (Jules), 1860—No. 7.

14.

**1874—Marcou** (Jules). Geological map of the world.

Accompanying "The Earth," by Élisée Reclus, 2d edition, Plate II. London, 1874.

See **Marcou** (Jules), 1860—No. 7.

15.

**1874—Marcou** (Jules). Carte géologique du monde.

Accompanying "La Terre," by Élisée Reclus, Plate II. German edition. (Berlin), 1874.

See **Marcou** (Jules), 1860—No. 7.

16.

**1875—Marcou** (Jules). Geological map of the world. Carte géologique de la terre. Scale 1: 23,000,000. Zurich, 1875.

Second edition, in eight sheets. North and South America are almost all colored, and many corrections and additions have been made. A reduction appeared in the fourth edition of Élisée Reclus's "La Terre," and also in translations and subsequent editions of the same work.

17.

**1875—Marcou** (Jules). Carte géologique de la terre, réduction et assemblage des huit feuilles.

Accompanying "Explication d'une seconde édition de la carte géologique de la terre." 4°. Zurich, 1875.

18.

**1876—Marcou** (Jules). Carte géologique du monde.

Accompanying "La Terre," by Élisée Reclus. Italian edition, from which the name of E. Reclus has been expunged. ———, 1876.

See **Marcou** (Jules), 1875—No. 16.

19.

**1876—Marcou** (Jules). Carte géologique du monde.

Accompanying "La Terre," by Élisée Reclus, 3ième édition, Plate II. Paris, 1876.

See **Marcou** (Jules), 1860.—No. 7.

20.

**1876—Marcou** (Jules). Carte géologique du monde.

Accompanying "La Terre," by Élisée Reclus. Carte géologique II. Magyar edition. Buda Pesth (Hungary), 1876.

See **Marcou** (Jules), 1875—No. 16.

21.

**1877—Marcou** (Jules). Carte géologique du monde d'après Jules Marcou.

Accompanying "La Terre," by Élisée Reclus, 4ième edition, Plate II, p. 26. Paris, 1877.

See **Marcou** (Jules), 1875—No. 16.

22.

**1877—Marcou** (Jules). Geological map of the world.

Accompanying "The Earth," by Élisée Reclus, 3d edition, Plate II. London, 1877.

See **Marcou** (Jules), 1875—No. 16.

23.

**1878—Marcou** (Jules). Carte géologique du monde.

Accompanying "La Terre," by Élisée Reclus. Carte II. Russian edition. St. Petersburg, 1878?

See **Marcou** (Jules), 1875—No. 16.

## NORTH AMERICA IN GENERAL, COMPRISING THE UNITED STATES, OR A LARGE PORTION OF THEM, AND THE BRITISH POSSESSIONS OF NORTH AMERICA.

24.

2—**Guettard** (Jean Étienne). Carte minéralogique où l'on voit la nature des terrains du Canada et de la Louisiane.

Accompanying "Mémoire dans lequel on compare la Canada à la Suisse par rapport à ses mineraux." Histoire de l'Académie Royale des sciences, 4°, p. 189, Plate VII. Paris, 1752.

A map extending from Florida to the 60th parallel of latitude north.

This very curious first "Geological Map of a part of North America," shows the geographical distribution of three large belts of rocks, which Guettard called "Bandes sabloneuse, marneuse, et schisteuse ou métallifère." The marly or clay belt is marked by a shaded zone, extending from the shores of Texas, on the Gulf of Mexico, toward the northeast as far Cape Breton Island, called Isle Royale; then it turns northwest toward Quebec. West of this band lay the schistose or metalliferous belt, and east of it the sandy belt under the sea-level.

Thirty-nine different signs and annotations indicate places where rocks and minerals exist between the Atlantic and the Rocky Mountains. On a smaller map, placed at the right-hand lower corner, on a larger scale, comprising the shores of the St. Lawrence River, Guettard points out eight localities containing fossils, which he figures on Plates 3 and 4. One is evidently an Orthis, and another a Leptæna, related to Leptæna sericea, both found on the shores or near Lake Champlain. Besides, Guettard gives figures of Crinoidœa and a tooth of the Mastodon giganteum, found on the banks of the Ohio River, in 1739, by Longueil, an officer of the French army, who collected there (Big bone Lick) bones, teeth, and tusks which still exist carefully kept among the collections of Comparative Anatomy at the "Jardin des Plantes," in Paris. The map was constructed by Philippe Buache for M. Guettard.

25.

3—**Maclure** (William). A map of the United States, colored geologically.

Accompanying "Observations on the Geology of the United States, explanatory of a Geological Map." Trans. Amer. Phil. Soc., Vol. VI, p. 411. Philadelphia, 1809.

This was published during the author's absence in Europe, and he was much dissatisfied with it.

26.

11—**Maclure** (William). Carte des États-Unis de l'Amérique-Nord, pour servir aux observations géologiques.

Accompanying "Observations sur la Géologie des États-Unis." (Journ. de Phys., de Chim., d'Hist. Nat. et des Arts, par J. C. Delamétherie, Vol. LXXII.) Paris, 1811.

For a fac-simile of this map see 1858—No. 54.

27.

**1817—Maclure** (William). Map of the United States of America, designed to illustrate the Geological Memoir of Wm. Maclure, esq.

Accompanying "Observations on the Geology of the United States of America." Trans. Amer. Phil. Soc., New Series, Vol. I. 4°. Philadelphia, 1817.

This geological map and the explanatory memoir are better known than the first map of 1809 or the French edition of 1811, and are generally considered as the starting point for the geology of North America. Also issued separately in 8°.

28.

**1822—Cleaveland** (Parker). (Geological Map) The United States.

Accompanying "An elementary treatise on Mineralogy and Geology, designed as a companion for travelers in the United States of America." Second edition in two volumes, p. 784, Vol. II, Plate VI. Boston, 1822.

This old geological map of the United States is merely a copy of the third edition of 1817, of Maclure's Geological Map, with very few additions or variations.

29.

**1822—Long** (S. H.) and **James** (Edwin). Map of the country drained by the Mississippi, western section.

Accompanying "Account of an expedition from Pittsburgh to the Rocky Mountains, performed in the years 1819 and 1820, under the command of Major S. H. Long," compiled by Edwin James, geologist to the expedition, 2 vol. and 4° atlas. Philadelphia, 1823.

In black, with dotted lines and geologic inscriptions indicating limits of the formations as understood then by Edwin James.

Although very rough, this first sketch of the geology of the country west of the Mississippi River, by Dr. Edwin James, is very creditable, and entitles him to be called the first pioneer of the geology of the country between the Mississippi River and the eastern foot of the Rocky Mountains. The volumes appeared in 1823 the atlas in 1822.

30.

**1842—Owen** (D. D.). Geological chart of the Ohio Valley.

Accompanying "On the geology of the Western States of North America" As a postponed paper in Journ. Geol. Soc., London, Vol. II, p. 433. London 1846.

This map was published in order to establish satisfactorily his just claim of original discoverer of many important points in the geology of the Western States, two maps having appeared in 1843, by B. Lawrence and J. Hall covering almost the same ground, without reference to the survey of David Dale Owen, from which they were compiled almost entirely.

31.

**1843—Lawrence** (Byrem). A geological map of the Western States.

[No place of publication]. 1843. Lithographed in Boston.

This very rare map is merely a copy of David Dale Owens' geological map of the Ohio Valley.

32.

**43—Hall** (James). Geological map of the Middle and Western States.

Accompanying "Geology of New York," Part IV, comprising the survey of the fourth geological districts. 4to. Albany, 1843; also issued separately.

33.

**43—Moxon** (Charles). Sketch of the geology of the United States.

Accompanying "On the geology of the United States." In the Geologist for the year 1843, edited by C. Moxon. Frontispiece. London, 1843.

A very rough reproduction and reprint of Maclure's geological map.

34.

**45—Lyell** (Sir Charles). Geological map of the United States, Canada, &c.

Accompanying "Travels in North America in the years 1841–42." London and New York, 1845.

This map appeared May 14th, 1845. It is important, giving for the first time a general view of the geology of North America.

35.

**846—Lyell** (Sir Charles). Geognostische Karte der Vereinigten Staaten, Canada, &c.

Accompanying "Reisen in Nord-Amerika von Charles Lyell. Deutsch, von Dr. Emil Th. Wolff." Halle, 1846.

36.

**848—Wislizenus** (A.). Geological sketch of a tour from Independence to Santa Fé, Chihuahua, Monterey, and Matamoros.

Accompanying "Memoir of a tour to Northern Mexico, connected with Colonel Doniphan's expedition in 1846 and 1847." Washington, 1848.

Black, with geological indications only.

37.

**51—Owen** (D. D.), **Norwood** (J. G.), and **Whittlesey** (Charles). Geological map of Wisconsin, Iowa, and Minnesota, exhibiting also the extension of the Iowa coal field into Missouri, and its relation to the Illinois coal field.

Accompanying "Report of a geological survey of Wisconsin, Iowa, and Minnesota and incidentally of a portion of Nebraska Territory," by D. D. Owen. Vol. of illustrations. 4°. Philadelphia, 1852.

A very important map for the upper Mississippi region. On the same large sheet, at the upper right-hand corner, there is also a "Geological map of the north shore of Lake Superior."

38.

**851—Owen** (D. D.), **Norwood** (J. G.), and **Whittlesey** (Charles). Geological map of the north shore of Lake Superior.

Accompanying "Report of a geological survey of Wisconsin, Iowa, and Minnesota and incidentally of a portion of Nebraska Territory," by D. D. Owen. Vol. of illustrations. 4°. Philadelphia, 1852.

See the preceding map—No. 37.

39.

**1852—Buch** (Leopold von). Geognostische Karte von Nord-Ame

Accompanying "Ueber die Juraformation auf der Erdfläche" in Monats der königlichen Akademie der Wissenschaften zu Berlin. Berlin, 185

It is the last memoir by the celebrated Prussian geologist. The m a very small scale, and was also issued separately.

40.

**1853—Marcou** (Jules). Geological map of the United States a British provinces of North-America.

Accompanying "A geological map of the United States and the provinces of North America, with an explanatory text, geological s and plates of the fossils which characterize the formation." Bosto 1853.

A French translation has appeared under the title "Carte géologi États-Unis et des provinces Britanniques de l'Amérique du Nord." panying "Voyage dans l'Amérique du Nord en 1853 et 1854, par Ch Lambert, Bruxelles, mars 1855. This map is the first which gives tribution of the strata, according to the nomenclature of Murchison Verneuil, into lower and upper Silurian and Devonian; it also extends the Mississippi as far as the Rocky Mountains.

41.

**1853—Hitchcock** (Edward). A geological map of the United Sta Canada.

Accompanying "Outlines of the geology of the globe, and of the States in particular, with two geological maps, and sketches of chara American fossils." Boston, 1854.

Sketch map made up by combining Boué's "Geological map of the with Charles Lyell and Jules Marcou's "Geological map of the Unite and Canada."

This map first appeared in October, 1853. Another issue was made

42.

**1854—Hitchcock** (Edward). A geological map of the United Sta Canada.

Second issue of the above-mentioned map—No. 41.

43.

**1855—Logan** (W. E.). Carte géologique du Canada. Scale: lieue au degré dont une = 4445 m.

Accompanying "Esquisse géologique du Canada pour servir à l'inte de la carte géologique envoyé à l'Exposition universelle de Paris en 1 W. E. Logan et T. Sterry Hunt, in 12°. Paris, 1855.

This map is also published in the "Bull. Soc. géol. France, 2e série, t page 1316. More than half of this map is of the United States.

44.

55—**Logan** (W. E.). Carte géologique du Canada. Scale, lieues de 25 au degré dont une = 4445 m.

Accompanying "Bull. Soc. géol. France," 2e série, tom. XII, p. 1316. Paris, 1855.

The same as the map mentioned above; a few copies were presented to the Geol. Soc. of France, and inserted in its Bulletin.

45.

55—**Lyell** (Sir Charles). Geological map of the United States, Canada, &c. London, 1855.

Second English edition. See **Lyell** (Sir Charles), 1845—No. 34.

46.

5—**Marcou** (Jules). Carte géologique des Etats-Unis et des provinces Britaniques de l'Amérique du Nord.

Accompanying "Voyage dans l'Amérique du Nord en 1853 et 1854", par Guillaume Lambert. Bruxelles, 1855.

See **Marcou** (Jules), 1853—No. 40.

47.

—**Marcou** (Jules). Carte du terrain Carbonifère dans une partie de l'Amérique du Nord.

Accompanying "Le terrain Carbonifère dans l'Amérique du Nord". La Bibliothèque universelle de Genève, Juin, 1855. Genève, 1855.

Black etching.

48

—**Marcou** (Jules). Geologische Karte der Vereinigten Staaten und Britischen Provinzen von Nord-Amerika. Scale, 1 : 14,000,000.

Accompanying "Ueber die Geologie der Vereinigten Staaten und der Englischer Provinzen von Nord-Amerika." Petermann's Geographische Mittheilungen. Vol I. Gotha, 1855.

Published July, 1855. It is the first geological map comprising the whole country from the Atlantic to the Pacific Oceans, the author being the first geologist to cross the continent with a Government expedition—the Pacific Railroad exploration. He was able to give said data by the 35th parellel of latitude from Arkansas to San Francisco.

49.

5—**Marcou** (Jules). Carte géologique des États-Unis et des provinces anglaises de l'Amérique du Nord.

Accompanying "Résumé explicatif d'une carte géologique des États-Unis et des provinces anglaises de l'Amérique du Nord." Bull. Soc. géol. France, tome XII, p. 813. Paris, 1855.

The number of the Bulletin for May, 1855, did not appear till the beginning of 1856. On this account the author, to prevent delays and in order to take date for his discoveries in the far West, had a German edition published in Petermann's Geographische Mittheilungen. This map also appeared in the Annales des Mines, tome VII, p. 329. Paris, 1855.

50.

**1855—Marcou** (Jules). Carte géologique des États-Unis et des provinces anglaises de l'Amérique du Nord.

Accompanying "Esquisse d'une classification des chaines de montagnes d'une partie de l'Amérique du Nord. Annales des Mines, 5e série, tome VII, p. 320, Plate IX. Paris, 1855.

See **Marcou** (Jules), 1855—No. 49.

51.

**1855—Rogers** (H. D.). Geological map of the United States and British North America.

Accompanying "Physical Atlas of Natural Phenomena," by Keith Johnston. Folio, Plate VIII. Edinburgh, 1856.

Published the 1st of July, 1856.

52.

**1857—Hall** (James), and **Lesley** (J. P.). Map illustrating the general geological features of the country west of the Mississippi.

Accompanying "Report on the United States and Mexican Boundary Survey," by W. H. Emory. 4°. Vol. I, Part II, p. 1. Washington, 1857.

53.

**1858—Mackie** (S. J.). Remnants of Primeval Lands, North America.

Accompanying "The remnants of the first life world and the bottom rocks." In "The Geologist," a popular monthly magazine of geology, edited by S. J. Mackie, p. 288. London, 1858.

54.

**1858—Maclure** (W.) Carte des États-Unis de l'Amérique du Nord, pour servir aux observations géologiques.

Accompanying "Geology of North America," by Jules Marcou. 4°. Zurich, 1858.

This is a copy on a somewhat smaller scale of the Paris edition of 1811.

See **Marcou** (Jules), 1858—No. 55.

55.

**1858—Marcou** (Jules). Carte géologique des États-Unis et des provinces anglaises de l'Amérique du Nord.

Accompanying "Geology of North America, with two reports on the prairies of Arkansas and Texas, the Rocky Mountains of New Mexico, and the Sierra Nevada of California." 4°. Zurich, 1858.

A reduction of this map, combined with the first edition of the "Geological map of the world," by the same author, is placed at the lower corner on the left-hand side of the sheet of "Geologie und Physikalische Karten," containing "Geologische Uebersichts-Karte der Erde nach Marcou, etc.," published by Artaria & Co. Vienna, 1872.

See **Marcou** (Jules), 1872—No. 66.

56.

**1861—Hayden** (F. V.). Outline reduction of the maps of Kansas, Nebraska, and Dakota. Scale, 60 miles to the inch.

Accompanying "On the geology and natural history of the Upper Missouri. Trans. Amer. Phil. Soc. 4°. Vol. XII, new series, article I, p. 218. Philadelphia, 1863.

57.

**1—Humphreys** (A. A.), and **Abbot** (H. L.). Map of the alluvial region of the Mississippi. Scale 1 : 1,500,000.

Accompanying "Report upon the physics and hydraulics of the Mississippi River," Professional Papers of the Corps of Topographical Engineers, United States Army, No. 4. 4°. Plate II, U. S. Mississippi Delta Survey. Philadelphia, 1861.

Very important and reliable map, not only in regard to the geological distribution of the alluvium, but also in regard to the delta and the mouth of the Mississippi.

58.

**1—Green** (W., jr.). Map showing the relation of the anthracite coal region to the great Appalachian coal-field, according to Leslie.

Accompanying "Notes on the anthracite coal region of North America. Trans. North of England Inst. Mining Engrs., Vol. XIII, p. 25. Newcastle-upon-Tyne, 1864.

59.

**1—Logan** (Sir W. E.). Geological map of Canada and the adjacent region, including parts of the British provinces, and of the United States.

Accompanying "Geol. Surv. of Canada, report of progress, from its commencement to 1863". Atlas of maps and sections, with an introduction and appendix I. Montreal, 1865.

Only one-sixth of the map is truly Canadian. In the map appears a Quebec group, comprising the Calciferous and Chazy limestone, and placed below the Trenton group and above the Potsdam. In the volume "Geology of Canada," the same Quebec group is placed above the Trenton group, and as a part of the Utica and Hudson River.

60.

**1—Marcou** (Jules). Carte des houillières des États-Unis d'après J. Marcou.

Accompanying "La vie souterraine, ou les mines et les mineurs," par Louis Simonin. 4°. Carte X, p. 112. Paris, 1867.

It is a reduction of Marcou's "Carte géologique des États-Unis et des Provinces anglaises de l'Amérique du Nord" of 1858.

61.

**1—Simonin** (Louis). Carte des gîtes miniers des Etats de la Californie et Nevada.

Accompanying "La vie souterraine, ou les mines et les mineurs." Carte XII, p. 432. Paris, 1867.

A reduction of a part of Marcou's "Carte géologique des États-Unis et des Provinces anglaises de l'Amérique du Nord" of 1858. It covers Oregon and some parts of Utah and Arizona.

62.

**1—Simonin** (Louis). Carte de la région métallifère du Lac Supérieur d'après Rogers et Marcou.

Accompanying "La vie souterraine, ou les mines et les mineurs." Carte XIV, p. 436. Paris, 1867.

63.

**1869—Forster** (J. W.). Geological sketch of the United States.

Accompanying "Resources of the Mississippi Valley." Page 272. Chicago, 1869. Black etching, covers one octavo page only.

64.

**1871—Credner** (Herman). Geognostische Karte des Alleghany-Systems. Nach den vorhandenen Arbeiten sowie eignen Unter-suchungen. Maasstab 1:6,000,000.

Accompanying "Die Geognosie und der Mineralreichthum des Alleghany-Systems." Erläuternder Text zur geognostischen Karte. Petermann's Geographische Mittheilungen. 4°. Vol. XVII, Taf. III. Gotha, 1871.

65.

**1872—Hitchcock** (C. H.) and **Blake** (W. P.). Geological map of the United States, compiled for the 9th Census. Washington, 1872.

The same as the map published in 1874.

See **Hitchcock** (C. H.) and **Blake** (W. P.), 1874—No. 70.

66.

**1872—Marcou** (Jules). Carte Géologique des États-Unis et des provinces anglaises de l'Amérique du Nord.

Accompanying "Physikalische Karten Geologie," published by Artaria & Co., on sheet containing "Geologische Uebersichtskarte der Erde nach Marcou." Vienna, 1872.

See **Marcou** (Jules), 1858—No. 55.

67.

**1873—Hitchcock** (C. H.) and **Blake** (W. P.). Geological map of the United States.

Accompanying "Statistics of mines and mining in the States and Territories west of the Rocky Mountains," being the fifth annual report of Rossiter W. Raymond, p. 480. Washington, 1873.

See **Hitchcock** (C. H.) and **Blake** (W. P.), 1874—No. 70.

68.

**1873—Macfarlane** (James). Map showing the coal fields of the United States.

Accompanying "The coal regions of America." New York, 1873.
Black etching.

69.

**1874—Hitchcock** (C. H.). Map of the coal fields of the United States, compiled from State reports.

Accompanying "Statistical atlas of the United States, based on the results of the Ninth Census, 1870, compiled under authority of Congress," by Francis A. Walker. Plates XI and XII. folio. Washington, 1874.

70.

**4—Hitchcock** (C. H.) and **Blake** (W. P.). Geological map of the United States, compiled from sources mentioned in the text.

Accompanying "Statistical atlas of the United States, based on the results of the Ninth Census, 1870, compiled under authority of Congress," by Francis A. Walker. Plates XIII and XIV. folio. Washington, 1874.

This map is wanting in uniformity of classification and clearness of definitions, not only for the rocks, but also for the colors, which do not represent the same formation on the right as on the left of the map; several copies dated 1872, with the following alteration in the title, "compiled for the Ninth Census," were privately distributed. It was distributed also at the Centennial Exhibition of Philadelphia, 1876, with the "Special report of the Smithsonian Institution." So it may be considered as an official "Geological map of the United States." It was also published in 1877 in "Gray's Atlas of the United States and the World." folio. Philadelphia.

See **Hitchcock** (C. H.) and **Blake** (W. P.), 1872—Nos. 65 and 67.

71.

**—Wrigley** (H. E.). Special oil report map A. Scale, 50 miles to the inch.

Accompanying "2nd Geo. Surv. of Pennsylvania." "Special Report on the Petroleum of Pennsylvania," Vol. J. Harrisburg, 1875.

Black etching, showing oil region of Eastern United States and Canada.

72.

**—Hitchcock** and **Blake**. Die Steinkohlenfelder der Vereinigten Staaten von N. A., nach der Karte von Hitchcock und Blake. Maassstab 1 : 13,500,000.

Accompanying "Statistische Uebersicht der Steinkohlengewinnung in der Nord-Amerikanischen Union." Von Alb. G. Gatschet in New-York. Petermann's Geographische Mittheilungen. 4°. Vol. XXI, 1875, Taf. XVI.

73.

**—Boyd** (E. F.). Geological map of the United States.

Accompanying "Remarks on the coal measures and oil produce of the United States of America, collected during a visit to that country in the autumn of 1875." Trans. North of England Inst. Mining Engrs., Vol. XXV, Plate XLIII, p. 188. Newcastle-upon-Tyne, 1876.

A rough copy of the map, published under authority of Congress, in Francis A. Walker's statistical atlas of the United States.

74.

**76—Boyd** (E. F.). Map of the coal fields of the United States.

Accompanying "Remarks on the coal measures and oil produce of the United States of America, collected during a visit to that country in the autumn of 1875." Trans. North of England Inst. Mining Engrs., Vol. XXV, Plate XLIV. Newcastle-upon-Tyne, 1876.

75.

**1876—Bradley** (F. H.). Geological chart of the United States east of the Rocky Mountains, and of Canada. New Haven, 1875.

A student's map in black etching.

76.

**1876—Hitchcock** (C. H.) and **Blake** (W. P.). Geological map of the United States.

Accompanying "Special report of the Smithsonian Institution for the Centennial." Washington, 1876.

See **Hitchcock** (C. H.) and **Blake** (W. P.), 1874—No. 70.

77.

**1877—Hitchcock** (C. H.) and **Blake** (W. P.). Geological map of the United States.

Accompanying "Atlas of the United States and the world," by Gray-Folio. Philadelphia, 1877.

See **Hitchcock** (C. H.) and **Blake** (W. P.), 1874—No. 70.

78.

**1878—Ratzel** (Friedr.). Geologische Karte der Vereinigten Staaten.

Accompanying "Die Vereinigten Staaten von Nord-Amerika, Vol. I, p. 93—München, 1878.

Perhaps a reduction of 3rd issue of the map by Hitchcock & Blake?

79.

**1879—Macfarlane** (J.). Geological sketch of the United States.

Accompanying "An American geological railway guide, giving the geological formation at every railway station," p. 216. New York, 1879.

In black etching and numbers. Very small, occupying one octavo sheet.

80.

**1879—Vivian** (A. P.). Geological map from Colorado to the Pacific. Scale 45 miles to the inch.

Accompanying "Wanderings in the western land." London, 1879.

Not seen.

81.

**1881—Hilgard** (E. W.). Map illustrating paper on the tertiary of the Gulf of Mexico.

Accompanying "The later tertiary of the Gulf of Mexico." Amer. Journ. Silliman, 3d series, Vol. XXII, Plate III. New Haven, 1881.

82.

**1881—Hitchcock** (C. H.). Geological map of the United States. Scale, 20 miles to the inch. New York, 1881.

With a pamphlet, a wall map 13 feet long and 8 feet wide; the largest geological map yet published of the United States and Canada.

## I.—ARCTIC AMERICA, COMPRISING GREENLAND, ARCTIC ARCHIPELAGO, AND THE NORTHERNMOST PART OF AMERICA.

83.

I—**Richardson** (Sir John). Map of the physical geography and geology of the Arctic regions.

Accompanying "Arctic searching expedition; a journal of a boat-voyage through Rupert's land and the Arctic Sea, in search of the discovery ships, under command of Sir John Franklin." 2 vols. London, 1851.

84.

—**Isbister** (A. K.). Geological sketch map of the northernmost parts of America.

Accompanying "On the geology of the Hudson's Bay Territories, and of portions of the Arctic and northwestern regions of America." In the Journ. Geol. Soc. London, Vol. XI, p. 497. London, 1855.

85.

—**Isbister** (A. K.). Geological sketch map of the northernmost parts of America.*

Accompanying "On the occurrence of numerous fragments of fir-wood in the islands of the Arctic Archipelago, with remarks on the rock specimens brought from that region," by Sir Roderick T. Murchison. From the Journ. Geol. Soc. London, Vol. XI, p. 536. London, 1855.

*This map was published in November of the same year, to accompany a separate issue of the above-mentioned memoir.

86.

—**Haughton** (S.). Discoveries in the Arctic Sea up to MDCCCLIV.

Accompanying "Reminiscences of Arctic ice travel in search of Sir John Franklin and his companions," by Capt. F. L. McClintock. With geological notes and illustrations by Rev. Samuel Haughton. Journal of the Royal Dublin Society, Feb., 1857. Dublin, 1857.

87.

—**Haughton** (S.). Geological map of the Arctic Archipelago.

Accompanying "A narrative of the Discovery of the fate of Sir John Franklin and his companions," by Capt. F. L. McClintock, p. 372. London, 1859.

In black etching, and covering more ground than the issue of 1857.

88.

**1860—Lieber** (O. M.). Sketch showing the geology of the coast of Labrador. Scale, 1 : 5,000,000.

Accompanying "Notes on the geology of the coast of Labrador," by Oscar M. Lieber, August, 1860 (sketch No. 38). Report of the Superintendent of the U. S. Coast Survey, showing the progress of the survey during the year 1860. 4°. Washington, 1861.

Black etching.

89.

**1861—Lieber** (O. M.). Die Küste von Labrador. Nach den bisherigen Englischen Aufnahmen, den Untersuchungen der Missionäre und handschriftlichen Mittheilungen von Oscar M. Lieber. Maasstab, 1 : 4,000,000.

Accompanying "Die Amerikanische astronomische Expedition nach Labrador in July, 1860." Petermann's Geographische Mittheilungen, Vol. VII, 1861, Taf. IX. 4°. Gotha, 1861.

90.

**1874—Rhode** (J. G.) and **Steenstrup** (K. J. V.). Geognostische Uebersichts-Karte der Küsten des Waigattes in Nord-Grönland. Maasstab, 1 : 710,000.

Accompanying "Bemerkungen zu der Geognostischen Uebersichts-Karte der Küsten des Waigattes in Nord-Grönland," von K. J. V. Steenstrup. (Geographie und Esforschung der Polarregionen, Nr. 89.) Petermann's Geographische Mittheilungen, Vol. XX, 1874, Taf. VII. Gotha, 1874.

Appeared also in Videnskabelige Meddelelser fra den naturhistoriske Forening i Kjobenhavn, 1874 and 1875, p. 74; and in the Mineralogical Magazine, Vol. I, p. 143. London and Truro, 1877.

91.

**1874—Rohde** (J. G.) and **Steenstrup** (K. J. V.). (Geognostische Uebersichts-Karte der Küsten des Waigattes in Nord-Grönland.)

Accompanying "Videnskabelige Meddelelser fra den naturhistoriske Forening i Kjobenhavn," 1874 and 1875, p. 74. Kjobenhavn, 1874.

See **Rohde** (J. G.) and **Steenstrup** (K. J. V.), 1874—No. 90.

Not seen.

92.

**1876—Steenstrup** (K. J. V.). Geognostisk Kaart over en Del af Julianehaabs Distrikt i Syd-Groenland.

Accompanying "A. Expeditionen til Julianehaabs Distrikt i 1876." Meddelelser om Groenland, Andet Hefte, p. 112. Kjobenhavn, 1881.

93.

**1877—Rohde** (J. G.) and **Steenstrup** (K. J. V.). Geognostische Uebersichts-Karte der Küsten des Waigattes in Nord-Grönland.

Accompanying "The Mineralogical Magazine," Vol. I, p. 143. "On the non-meteoric origin of the masses of metallic iron in the basalt of Disko, Greenland." Selected and translated from the original Danish paper by K. J. V. Steenstrup, by J. G. Rohde, traveling companion to the author on his expedition in 1872. London and Truro, 1877.

In the copy seen there is no map.

94.

78—**Feilden** (H. W.) and **De Rance** (C. E.). Sketch map showing the geology of Grinnell Land and the neighboring regions.

Accompanying "Geology of the coasts of the Arctic lands visited by the late British expedition, under Captain Sir George Nares." Journ. Geol. Soc. London, Vol. XXXIV, p. 556. London, 1878.

Black etching.

95.

79—**Kornerup** (A.). Geologisk Kaartskizze over Kystlandet fra Godthaab til Tiningnertok:

Accompanying "Geologiske Iagttagelser fra Vestkysten af Groenland." Meddelelser om Groenland, Foerst Hefte, Kaart B. Kjobenhavn, 1879.

96.

80—**Kornerup** (A.). Geologisk Kaartskisse over Gnejsens Strygningslinjer fra Kangatsiak til Holstensborg.

Accompanying "B. Expeditionen til Holstensborgs og Egedesmindes Distrikter i 1879." Meddelelser om Groenland, Andet Hefte, p. 149. Kjobenhavn, 1881.

## IV.—NEWFOUNDLAND.

97.

**1824—Cormack** (W. E.). Map of Newfoundland.

Accompanying "Account of a journey across the island of Newfound Edinburgh Philosophical Journal, Vol. X, Plate VI, page, 156. Edin 1824.

Black, with geological indications.

98.

**1842—Bonnycastle** (Sir Richard H.). Newfoundland, in 1842, consi in its geological and statistical relations.

Acompanying "Newfoundland in 1842." 2 vols. 12°. London, 184

Black, with geological indications and notes.

Jukes has priority of Bonnycastle, who took advantage of and copied official report to the Newfoundland Government.

99.

**1842—Jukes** (J. B.). Map of the island of Newfoundland.

Accompaning "Excursions in and about Newfoundland during th 1839 and 1840," by J. B. Jukes. 2 vols. London, 1842.

Black, with geological inscriptions and signs.

See **Jukes** (J. B.), 1843—No. 100.

100.

**1843—Jukes** (J. B.). Map of the island of Newfoundland (geolo colored).

Accompanying "General report of the geological survey of Newfou during the years 1839 and 1840." London, 1843.

About a quarter of the whole island is colored geologically; the res in blank, as unknown. An important work. The same map, but not ically colored, only with the geological inscriptions and signs, accon "Excursions in and about Newfoundland during the years 1839 and 18 J. B. Jukes. In two volumes. London, 1842.

101.

**1866—Murray** (Alex.). Plan of Belvie Bay (Newfoundland). S miles to 1 inch.

Accompanying "Report on the geology of Newfoundland for 1865, Montreal, 1866.

Black, with geological indications.

102.

0—**Murray** (Alex.). Map of an exploration of the Bay East River, Newfoundland. Scale, 4 statute miles to 1 inch.

Accompanying "Report upon the geological survey of Newfoundland for the year 1870." St. John's, Newfoundland, 1870.

Black, with geological indications.

103.

73—**Murray** (Alex.). Geological map of Newfoundland. London, 1873.

The first complete geological map of the whole island. No date of publication on the map; but a small explanatory tract or label attached to it says July, 1873.

104.

3—**Murray** (Alex.) and **Howley** (J. P.). Map showing the distribution of the coal formation, &c., St. George's Bay, Newfoundland.

Accompanying "Report of progress for the year 1873, Geological survey of Newfoundland." Montreal, 1873.

Black, with dotted lines and geological indications.

105.

—**Gilpin** (E.). Sketch of the Carboniferous district of St. George's Bay, Newfoundland.

Accompanying "Notes on the Coalmeasures and lower Carboniferous strata of Western Newfoundland." Trans. North of England Inst. Mining Engrs., Vol. XXIII, Plate XXXV. Newcastle-upon-Tyne, 1874.

Black etching and geological indications.

106.

—**Murray** (Alex.). Map of Gander River and Lake. Scale, 4 miles to 1 inch.

Accompanying "Geological survey of Newfoundland; report of progress for the year 1874." St. John's, Newfoundland, 1875.

Black, with geological indications.

107.

—**Murray** (Alex.) and **Howley** (J. P.). Map showing the distribution of the Silurian and Carboniferous formation, &c., in St. George's and Port à Port Bays, Newfoundland. Scale, 4 miles to 1 inch.

Accompanying "Geological survey of Newfoundland; report of progress for for the year 1874." St. John's, Newfoundland, 1875.

Black, with dotted lines and geological indications.

108.

79)—**Murray** (Alex.) and **Howley** (J. P.) Geological map of Newfoundland. London (1879).

There is no date of publication on the map. I received a copy from the author in July, 1880.

109.

1881—**Murray** (Alex.) and **Howley** (J. P.) Peninsula of Avalon, showing distribution of formations. Scale, 4 miles to 1 inch.

Accompanying "Geological survey of Newfoundland; report of progress for the year 1881." St. John's, Newfoundland, 1882.

A large, important geological map of the eastern part of the island.

110.

1881—**Howley** (J. P.). Section map showing the corrugation effecting the stratification of the Huronian formation near Brigus, Conception Bay. Scale, 4 inches to 1 mile.

Accompanying "Geological survey of Newfoundland; report of progress for the year 1881. St. John's, Newfoundland, 1882.

## ACADIA, COMPRISING NOVA SCOTIA (CAPE BRETON ISLAND), PRINCE EDWARD ISLAND, MAGDALEN ISLANDS, AND NEW BRUNSWICK.

111.

**Jackson** (C. T.) and **Alger** (Francis). A geological map of part of Nova Scotia. Scale, 10 miles to $\frac{8}{8}$ of an inch.

Accompanying "A description of the mineralogy and geology of a part of Nova Scotia." Amer. Journ. Silliman, Vol. XIV. New Haven, 1828.

Also in the Memoirs of the American Academy of Science, 1832. 4°. Cambridge.

112.

**Baddeley** (F. F.). Outline of the Magdalen Islands, with geological notes.

Accompanying "On the Magdalen Islands." In Trans. Lit. and Hist. Soc. Quebec. Vol. II. Quebec, 1836.

113.

**Jackson** (C. T.) and **Alger** (Francis). A geological map of part of Nova Scotia. Scale, 10 miles to $\frac{8}{8}$ of an inch.

Accompanying "A description of the mineralogy and geology of a part of Nova Scotia." Memoirs of the American Academy of Science. 4to. 1832. Cambridge, 1832.

See **Jackson** (C. T.) and **Alger** (Francis), 1828—No. 111.

114.

**Gesner** (Abraham). A new map of Nova Scotia and Cape Breton, Prince Edward Island, and part of New Brunswick.

Accompanying "Remarks on the geology and mineralogy of Nova Scotia," by A. Gesner. Halifax, 1836.

No author's name on the map.

115.

**Jackson** (C. T.) and **Alger** (F.). A new pocket map of the peninsula of Nova Scotia, intended as a topographical guide, also to illustrate its geological structure. (Boston), 1841.

No place of publication is given, but Boston is undoubtedly the place and Francis Alger was the editor.

116.

**Gesner** (Abraham). Geological map of Nova Scotia.

Accompanying "On the geology of Cape Breton," by Richard Brown, and "In the lower carboniferous rocks or gypsiferous formation of Nova Scotia," by J. W. Dawson. Journ. Geol. Soc. London, Vol. I, p. 23. London, 1845.

See **Dawson** (J. W.), 1845—No. 119.

117.

**1843—Gesner** (Abraham). Geological map of Nova Scotia.

Accompanying "A geological map of Nova Scotia"; also, "On the ge Cape Breton," by Richard Brown, and "On the lower carboniferous Nova Scotia," by J. W. Dawson. Proceed. of the Geol. Soc. of Lond VI, pp. 186, 269, and 272." London, 1846.

A part of the map was colored by Messrs. R. Brown and J. W. ] and the geological map by C. T. Jackson and Alger of 1828 was used.

118.

**1845—Dawson** (J. W.). Geological map of part of Nova Scotia.

Accompanying "On the newer coal formation of the eastern part Scotia." Journ. Geol. Soc. London, Vol. I, p. 322. London, 1845.

See **Dawson** (J. W.), 1845—No. 119.

119.

**1845—Dawson** (J. W.). Geological map of part of Nova Scotia.

Accompanying "On the newer coal formation of the eastern part Scotia." In Proceed. of the Geol. Soc. of London, Vol. IV, p. 504. 1846.

This map and A. Gesner's geological map of Nova Scotia were issue first in Vol. IV of the Proceedings and then in Vol. I of the Journ Geological Society. No explanation is given of the double issue of n of the accompanying memoirs.

120.

**1847—Dawson** (J. W.). Map and sections of new red sands Nova Scotia.

Accompanying "On the new red sandstone of Nova Scotia." Jou Soc. London, Vol. IV, p. 50. London, 1848.

Black etching.

121.

**1848—Taylor** (R. C.). Map of the New Brunswick, Nova Scoti Breton, and Newfoundland coal fields.

Accompanying "Statistics of coal," p. 208. Philadelphia, 1848.

122.

**1850—Robb** (J.). Geological map of New Brunswick.

Accompanying "Report on the agricultural capabilities of the pr New Brunswick," by James F. W. Johnston. Fredericton, 1850.

The main sources of information for the construction of this map manuscript maps by Abraham Gesner, formerly provincial geologist.

123.

**1851—Jackson** (C. T.). A geological map of the Albert Coal Mi the surrounding strata.

Accompanying "Report on the Albert Coal Mine" (New Brunswick ton), 1851.

Black, with geological indications.

124.

5—**Dawson** (J. W.). Geological map of Nova Scotia, Prince Edward Island, and part of New Brunswick.

Accompanying "Acadian geology: an account of the geological structure and mineral resources of Nova Scotia and portions of the neighbouring provinces of British America." Edinburgh, 1855.

The first edition of an important geological map and work.

125.

D—**Dawson** (J. W.). No title.

Accompanying "On the Silurian and Devonian rocks of Nova Scotia." The Canadian Naturalist and Geologist, Vol. V, p. 133. Montreal, 1860.

Black etching.

126.

3—**Matthew** (G. F.). Map of the vicinity of St. John, New Brunswick.

Accompanying "Observations on the geology of St. John County, New Brunswick." The Canadian Naturalist and Geologist, p. 8, Montreal, 1863.

Black etching.

127.

1—**Bailey** (L. W.). Geological map of the Tobique and Nepisiquit Rivers, New Brunswick.

Accompanying "Notes on the geology and botany of New Brunswick." The Canadian Naturalist and Geologist, new series, Vol. I, p. 81. Montreal, 1864.

Black etching.

128.

1—**Bailey** (L. W.) and **Matthew** (G. F.). Geological map of the counties of St. John, Kings, Queens, and Albert, New Brunswick, showing the position and extent of each formation, from the Carboniferous basin to the coast.

Accompanying "Observations on the geology of Southern New Brunswick, made principally during the summer of 1864," by L. W. Bailey, George F. Matthew, and C. F. Hart. Fredericton, 1865.

An important map and memoir.

129.

5—**Bailey** (L. W.) and **Matthew** (G. F.). Geological map of the counties of St. John, Kings, Queens, and Albert, New Brunswick, showing the position and extent of each formation, from the Carboniferous basin to the coast.

Accompanying "On the Azoic and Paleozoic rocks of Southern New Brunswick," by by G. F. Matthew. Journ. Geol. Soc. London, Vol. XXI, p. 422. London, 1865.

Black etching.

130.

**1865—Bailey** (L. W.). Geological map of Grand Manan.
Accompanying "On the physiography and geology of the islan Manan" (New Brunswick). The Canadian Naturalist and Geolog p. 43. Montreal, 1865.
Black etching.

131.

**1865—Hedley** (Edward). Geological map of the province Scotia, including the island of Cape Breton.
Accompanying "On the iron mines and iron manufacture of N Trans. North of England Inst. Mining Engrs., Vol. XIV, Plate I, Newcastle-upon-Tyne, 1865.

132.

**1866—Honeyman** (D.). (Geological) map of Antigonish Coun
Accompanying "Geology of Antigonish County, Nova Scotia. and Trans. of the Nova Scotian Institute of Natural Sciences of H Scotia. Vol. I, p. 106. Halifax, 1867.

133.

**1868—Dawson** (J. W.). Sketch map of Pictou coal district.
Accompanying "Acadian geology," 2d edition, p. 320. London, Black etching and inscriptions.

134.

**1868—Dawson** (J. W.). Map of Cape Breton coal fields.
Accompanying "Acadian geology," 2d edition, p. 413. London, Black etching and inscriptions.
These two maps of Dawson are copied in black etching, on a re wood cuts, in "Coal regions of America," by James Macfarlane, 1873.

135.

**1868—Dawson** (J. W.). Geological map of Nova Scotia, Ne wick, and Prince Edward's Island. Scale, 25 miles to
Accompanying "Acadian geology," 2d edition and 3d edition 1868 and 1878.

136.

**1869—Robb** (Charles). Sketch map of the counties of York, and part of Victoria, province of New Brunswick. Sca to 1 inch.
Accompanying "Geological survey of Canada. Report of pr 1866 to 1869," p. 173. Montreal, 1870.
Black, with geological indications.

137.

70—**Hind** (H. Y.). Sketch maps from the Atlantic at Halifax to the St. Lawrence.

Accompanying "On two Gneissoid series in Nova Scotia and New Brunswick, supposed to be the equivalent of the Huronian and Laurentian." Journ. Geol. Soc. London, Vol. XXVI, p. 478. London, 1870.

Three sketches in black etchings.

138.

70—**Logan** (Sir W. E.), and **Hartley** (E.). Geological map of the Pictou coal field, province of Nova Scotia. Scale, 1 inch to 8 mile.

Accompanying "Geological survey of Canada, report of progress from 1866 to 1869," p. 3. Montreal, 1870.

139.

70—**Rutherford** (John). Map of Nova Scotia, showing the Carboniferous formation and position of the coal fields.

Accompanying "The coal fields of Nova Scotia." Trans. North of England Inst. Mining Engrs., Vol. XIX, Plate XXV, p. 114. Newcastle-upon-Tyne, 1870.

Black etching.

140.

70—**Rutherford** (John). Map of portion of the Pictou coal field.

Accompanying "The coal fields of Nova Scotia." Trans. North of England Inst. Mining Engrs., Vol. XIX, Plate XXVII, p. 122. Newcastle-upon-Tyne, 1870.

Black, with geological indications.

141.

71—**Brown** (Richard). Geological map of Cape Breton.

Accompanying "The coal fields and coal trade of the Island of Cape Breton." Frontispiece. London, 1871.

142.

71—**Brown** (Richard). Map of the Sydney coal field.

Accompanying "The coal fields and coal trade of the Island of Cape Breton," p. 166. London, 1871.

143.

71—**Dawson** (J. W.). Geological map of Prince Edward Island.

Accompanying "Report on the geological structure and mineral resources of Prince Edward Island," by J. W. Dawson, assisted by B. J. Harrington. Montreal, 1871.

144.

73—**Dawson** (J. W.). Sketch map of Pictou coal district.

Accompanying "Coal regions of America," by James Macfarlane. New York, 1873.

Black etching. A reduction of Dawson's map of 1868.

See Dawson (J. W.), 1868—No. 133.

145.

**1873—Dawson** (J. W.). Map of Cape Breton coal field.

Accompanying "Coal regions of America," by James Macfarla York, 1873.

Black etching. A reduction of Dawson's map of 1868.

See **Dawson** (J. W.), 1868—No. 134.

146.

**1873—Gilpin** (E.). Picton coal field. Scale, two-thirds of an in one mile.

Accompanying "The Picton coal field." Trans. North of Eng Mining Engrs., Vol. XXII, Plate XXXIII, p. 139. Newcastle-u 1873.

Black etching and geological indications.

147.

**1875—Gilpin** (E.). Sketch map Sydney coal field from admiralt

Accompanying "The submarine coal of Cape Breton, Nova Scotia North of England Inst. Mining Engrs., Vol. XXIV, Plate XXXIV. tle-upon-Tyne, 1875.

Black etching.

148.

**1875—Robb** (C.) and **Fletcher** (H.). Geological map of Cape district, Cape Breton, Nova Scotia. Scale, four incl mile.

Accompanying "Report on explorations and surveys in Cap Nova Scotia." Geological Surv. of Canada; report of progress fo p. 251. Montreal, 1875.

149.

**1875—Robb** (C.) and **Fletcher** (H.). Geological map of the Syd field, Cape Breton, Nova Scotia. Scale, one inch to a n

Accompanying "Report of explorations and surveys in Cape Br Scotia," by H. Fletcher. Geol. Surv. Canada; report of progress fc p. 418. Montreal, 1877.

150.

**1875—Routledge** (W.). Coal area map or plan of the Sydney c Cape Breton County, Nova Scotia.

Accompanying "Notes on the Sydney coal field in the Island of Ca British North America." Trans. North of England Inst. Mining E XXIV, Plate XXXVI. Newcastle-upon-Tyne, 1875.

151.

**1876—Bailey** (L. W.) and **Ells** (R. W.). Geological map of t carboniferous rocks of Albert and Westmoreland Count Brunswick, showing the distribution of the Albert shales one inch to a mile.

Accompanying "Report on the lower carboniferous belt of A Westmoreland Counties, N. B., including the 'Albert shales.'" ( Canada; report of progress for 1876-'77, p. 351. Montreal, 1878.

152.

1876—**Ells** (R. W.). Map shewing the distribution of iron ores of Carleton County, New Brunswick.

Accompanying "Report on the iron ore deposits of Carleton County, New Brunswick." Geol. Surv. Canada; report of progress for 1874–'75, p. 97. Montreal, 1876.

Black, with geological indications.

153.

1876—**Fletcher** (H.). Geological map of part of Cape Breton, Nova Scotia, from North Sydney and Sydney River to Great Bras d'Or and St. Anne Harbor. Scale, one inch to a mile.

Accompanying "Report on the geology of part of the counties of Victoria, Cape Breton, and Richmond, Nova Scotia." Geol. Surv. Canada; report of progress for 1876–'77, p. 456. Montreal, 1878.

154.

1876—**Robb** (C.) and **Fletcher** (H.). Geological map of the Sydney coal field, Cape Breton, Nova Scotia. Scale, one inch to a mile.

Accompanying "Report on exploration and surveys in Cape Breton, Nova Scotia." Geol. Surv. Canada; report of progress for 1874–'75, p. 266. Montreal, 1875.

155.

1877—**Gilpin** (E.). Geological map of Nova Scotia, shewing relative positions of the iron ores, limestones and coal fields, based on the geological map prefixed to second edition of Dr. Dawson's Acadian Geology.

Accompanying "The iron ores of Nova Scotia." Trans. North of England Inst. Mining Engrs., Vol. XXVI, Plate IX. Newcastle-upon-Tyne, 1877.

156.

1877—**Gilpin** (E.). Geological map of part of Pictou County, Nova Scotia, from surveys of Sir William Logan and the writer.

Accompanying "The iron ores of Nova Scotia." Trans. north of England Inst. Mining Engrs. Vol. XXVI, Plate VIII. Newcastle-upon-Tyne, 1877.

157.

1878—**Dawson** (J. W.). Geological map of Nova Scotia, New Brunswick, and Prince Edward's Island. Scale, 25 miles to the inch.

Accompanying "Acadian geology," 3d edition. London, 1878.

The map is precisely the same as that in the 2d edition, published in 1868.

See **Dawson** (J. W.), 1868—No. 135.

158.

1879—**Fletcher** (H.). Geological map of part of Cape Breton, Nova Scotia, to illustrate Report for 1877–8. Scale, one inch to a mile.

Accompanying "Reports of explorations and surveys in Cape Breton, Nova Scotia." Geol. Surv. Canada; report of progress for 1877–'78, atlas. Montreal, 1879.

159.

**1880—Bailey** (L. W.), **Matthew** (G. F.), and **Ells** (R. W.). Province of New Brunswick. Scale, 4 miles to one inch, or 1:253,440.

Accompanying "Report on the geology of southern New Brunswick, embracing the counties of Charlotte, Sunbury, Queens, King, St. John, and Albert." Geol. Surv. Canada; report of progress for 1878–79. Montreal, 1880.

The southern part of New Brunswick, No. 1, in three sheets, Nos. 1, S. W., 1, S. E., and 1, N. E.

This map is remarkably well executed.

160.

**1881—Gilpin** (Edwin). Sketch map, approximate distribution of the carboniferous series of Nova Scotia and New Brunswick.

Accompanying "The gypsum of Nova Scotia." Trans. North of England Inst., Mining Engrs., Vol. XXX, Plate XII, p. 68. Newcastle-upon-Tyne, 1881.

—CANADA PROPER, COMPRISING THE PROVINCE OF QUEBEC (ANTICOSTI ISLAND) OR LOWER CANADA OR EAST CANADA, AND THE PROVINCE OF ONTARIO OR UPPER CANADA OR WEST CANADA.

161.

**9—Baddeley** (F. F.). Sketch of the river Saguenay and Lake St. John, to which are added a few geognostical notes.

Accompanying "Geognosy of a part of the Saguenay country." In Trans. Literary and Historical Soc., Quebec, Vol. I. Quebec, 1829.

Black, with geological indications.

162.

**2—Logan** (W. E.). Geological map of a part of Canada.

Accompanying "On the foot-prints occurring in the Potsdam sandstone of Canada." Journ. Geol. Soc., London, Vol. VIII, p. 199. London, 1852.

This map is of a part of Canada East.

163.

**3—Bigsby** (J. J.). Geological map of the vicinity of Quebec.

Accompanying "On the geology of Quebec and its environs." Journ. Geol. Soc., London, Vol. IX, p. 82. London, 1853.

Black etching.

164.

**8—Logan** (W. E.). Plan showing the distribution of crystalline limestones of the Laurentian series, between Grenville and Rawdon. Scale, 3 miles to an inch.

Accompanying "Geol. Surv. Canada; reports of progress for the years 1853-56", p. 38. Toronto, 1857.

165.

**6—Richardson** (James). Plan of the Island of Anticosti. Scale, 9 miles to an inch.

Accompanying "Geol. Surv. Canada; report of progress for the years 1853-56", p. 234. Toronto, 1857.

Black, with dotted lines, letters, and indications.

166.

**7—Murray** (Alex.). Plans of Bonne Chère, Madawaska, and Shawashkong Rivers, and sources of the Ottonabee. Scale, 80 chains to an inch.

Accompanying "Geological Reports of Canada for 1853, '54, '55, '56." Grand folio atlas. Toronto, 1857.

In four sheets. Black, with geological indications.

167.

**1857—Murray** (A.) and **Logan** (W. E.). Plans shewing explor the north shore of Lake Huron and thence eastward t tawa. Scale, 80 chains to an inch.

Accompanying "Geographical Reports of Canada for 1853, '54 Grand folio atlas. Toronto, 1857.

In eleven sheets. Black, with geological indications.

168.

**1857—Murray** (A.) and **Logan** (W. E.). Plans shewing explora tween the east shore of Lake Huron and the Ottaw Maganatawan River, and Muskoka and Petewahweh Scale, 80 chains to an inch.

Accompanying "Geological Reports of Canada for 1853, '54, Grand folio atlas. Toronto, 1857.

In seven sheets. Black, with geological indications.

169.

**1857—Richardson** (James). Plan showing the distribution of vonian and Silurian formations in a part of Gaspé. Scal to an inch.

Accompanying "Geol. Surv. Canada; report of progress fo 1857", p. 270. Toronto, 1858.

Black, with dotted lines and geological indications.

170.

**1857—Richardson** (J.) and **Barlow** (S.). Topographical plan of M River.

Accompanying "Geol. Surv. Canada; report of progress for 1857", p. 92. Toronto, 1858.

Black, with geological indications.

171.

**1857—Richardson** (J.). Plan showing the distribution of the La and Lower Silurian rocks in the vicinity of Lake St. Joh

Accompanying "Geol. Surv. Canada; report of progress for 1857", p. 92. Toronto, 1858.

Black, with geological indications.

172.

**1858—Logan** (Sir W. E.). Plan showing the distribution of or limestone of the Laurentian series in the counties of Ar and Ottawa.

Accompanying "Geol. Surv. of Canada; report of progress for 1858", p. 66. Montreal, 1859.

Black, with geological indications.

173.

58—**Logan** (Sir W. E.). Plan showing the distribution of the Huronian rocks, between rivers St. Mary and Missisague.

Accompanying "Geol. Surv. Canada; report of progress for the year 1858", p. 104. Montreal, 1859.

Black, with geological indications.

174.

58—**Richardson** (J.). Plan showing the distribution of the Devonian and Silurian formations in a part of Gaspé.

Accompanying "Geol. Surv. of Canada; report of progress for the year 1858", p. 170. Montreal, 1859.

Black, with geological indications.

175.

D—**Gibb** (G. D.). Murray's cavern and subterranean river—Fourth chute of the Bonne Chère River, Ottawa.

Accompanying "On Canadian Caverns;" The Geologist, edited by J. S. Mackie, Vol. III, pl. XI. London, 1860.

Colored, and with geological indications.

176.

D—**Gibb** (G. D.). Basaltic dykes of Mecattina.

Accompanying "On Canadian Caverns;" The Geologist, edited by J. S. Mackie, Vol. III, pl. VIII. London, 1860.

Colored, and with geological indications.

177.

D—**Gibb** (G. D.). The basaltic caverns of Henley Island.

Accompanying "On Canadian Caverns;" The Geologist, edited by J. S. Mackie, Vol. III, pl. VII. London, 1860.

178.

D—**Gibb** (G. D.). Caverns and arched rocks at Percé Gaspé.

Accompanying "On Canadian Caverns;" The Geologist, edited by J. S. Mackie, Vol. III, pl. VI. London, 1860.

Colored, and with geological indications.

179.

2—**Logan** (Sir W. E.). Map showing the distribution of Laurentian rocks in parts of the counties of Ottawa, Terrebonne, Argenteuil, and Two Mountains. Scale, 7 miles to 1 inch.

Accompanying "Geol. Surv. Canada; report of progress from its commencement to 1863." Atlas of maps and sections, with an introduction and appendix. Geological maps II. Montreal, 1865.

180.

**1862—Logan** (Sir W. E.). Plan showing the distribution of lir conglomerates in the Quebec group, of Point Lévis.

Accompanying "Geol. Surv. Canada; report of progress from mencement to 1863." Atlas of maps and sections, with an introductio pendix. Geological maps V. Montreal, 1865.

Black etching.

See **Logan** (Sir W. E.), 1862—No. 181.

181.

**1862.—Logan** (Sir W. E.). Plan showing the distribution of lir conglomerates in the Quebec group at Point Lévis.

Accompanying "Letter addressed to Mr. Joachim Barrande, on th the Quebec group at Point Lévis," in The Canadian Naturalist and ( May and June, 1863. Vol. VIII, p. 183. Montreal, June, 1863.

Black etching.

182.

**1863—Marcou** (Jules). Plan des gisements des lentilles dolor dans les schistes Taconiques de la Pointe Lévis, au Canad 1863.

Accompanying "Notice sur les gisements des lentilles trilobitifèr ques de la Pointe Lévis, au Canada." Bull. Soc. géol. France, 2e s XXI, p. 236. Paris, 1864.

Black etching.

183.

**1865—Logan** (Sir W. E.). Map showing the distribution of var perficial deposits between Lake Superior and Gaspé. Sc miles to the inch.

Accompanying "Geol. Surv. Canada; report of progress from mencement to 1863." Atlas of maps and sections, with an introdu appendix. Geological maps VI. Montreal, 1865.

184.

**1865—Logan** (Sir W. E.). Map showing the distribution of the H rocks between rivers Bachehwahnung and Mississagui. 1.506,880, or 8 miles to the inch.

Accompanying "Geol. Surv. Canada; report of progress from its cc ment to 1863." Atlas of maps and sections, with an introduction and a Geological maps III. Montreal, 1865.

185.

**1865—Logan** (Sir. W. E.). Map showing the distribution of r longing to the Potsdam, Quebec, and Trenton groups, on side of Lake Champlain, in the neighbourhood of the line l Canada East and Vermont. Scale, two miles to an inch.

Accompanying "Geol. Surv. Canada; report of progress from mencement to 1863." Atlas of maps and sections, with an introdu appendix. Geological maps IV. Montreal, 1865.

186.

1868—**Richardson** (James). Map showing the distribution of the Lower Silurian rocks between the Chaudière and Trois Pistoles Rivers, south side of the river St. Lawrence, province of Quebec. Scale, eight miles to one inch.

Accompanying "Geol. Surv. Canada; report of progress from 1866 to 1869", p. 119. Montreal, 1870.

187.

1868—**Vennor** (H. G.). Map showing the distribution of the rock formations in parts of the counties of Peterborough, Hastings, Addington, and Frontenac, province of Ontario. Scale, 4 miles to one inch.

Accompanying "Geol. Surv. Canada; report of progress from 1866 to 1869", p. 143. Montreal, 1870.

188.

1874—**Vennor** (H. G.). Plan of a portion of North Burgess, shewing position of apatite openings. Scale, half a mile to an inch.

Accompanying "Report of explorations and surveys in Fontenac, Leeds, and Lanark Counties," Geol. Surv., Canada; report of progress for 1873-74, p. 128. Montreal, 1874.

Black etching, and geological indications.

189.

1876—**Vennor** (H. G.). Map of Lanark County and parts of Renfrew and Leeds, province of Ontario. Geologically shaded. Scale, 4 miles to one inch.

Accompanying "Report of explorations in the rear portions of Frontenac and Lanark Counties, etc." Geol. Surv. of Canada; report of progress for 1874-'75, p. 105. Montreal, 1876.

190.

1877—**Vennor** (H. G.). Map of Ottawa County. Scale, 4 miles to one inch.

Accompanying "Report of Ottawa County." Geol. Surv. of Canada; report of progress for 1876-'77, p. 320. Montreal, 1878.

191.

1880—**Dawson** (J. W.). Western Canada.

Accompanying "Lecture notes on geology and outline of the geology of Canada." Montreal, 1880.

Black etching.

192.

1880—**Dawson** (J. W.). Eastern Canada.

Accompanying "Lecture notes on geology and outline of the geology of Canada." Montreal, 1880.

Black etching.

## VII.—NEW ENGLAND, COMPRISING MAINE, NEW HAMPSHIRE, VERMONT, MASSACHUSETTS, RHODE ISLAND, AND CONNECTICUT.

193.

**1817—Hitchcock** (E.). A geological map of a part of Massachusetts on Connecticut River.

Accompanying "Remarks on the geology and mineralogy of a section on Massachusetts on Connecticut River, with a part of New Hampshire and Vermont." Amer. Journ., Silliman. Vol. I. New York, 1819.

194.

**1818.—Dana** (J. F.) and **Dana** (S. L.) A geological map of Boston and its vicinity.

Accompanying "Outlines of the mineralogy and geology of Boston and its vicinity," with a geological map. Boston, 1818.

195.

**1819—Dewey** (C.). A geological map of the northwest part of Massachusetts. Scale, 2 miles to the inch.

Accompanying "Sketch of the mineralogy and geology of the vicinity of Williams College, Williamstown, Mass." Amer. Journ., Silliman. Vol. I. New York, 1819.

196.

**1822—Hitchcock** (E.). A geological map of the Connecticut. Scale, 5 miles to $\frac{3}{4}$ of an inch.

Accompanying "A sketch of the geology, &c. of the regions contiguous to the river Connecticut." Amer. Journ., Silliman. Vol. VI. New Haven, 1823.

197.

**1824—Dewey** (C.). A geological map of the county of Berkshire, Mass., and of a small part of the adjoining States.

Accompanying "A sketch of the geology and mineralogy of the western part of Massachusetts and a small part of the adjoining States." Amer. Journ. Silliman. Vol. VIII. New Haven, 1824.

198.

**1824—Hitchcock** (E.) Outlines of the geology of Martha's Vineyard, &c.

Accompanying "Notices of the geology of Martha's Vineyard and the Elizabeth Islands." Amer. Journ. Silliman. Vol. VII, p. 336, Plate IV. New Haven, 1824.

Reprinted in Journal of Science of the Royal Institution of London, February, 1824.

199.

1827—**Nash** (A.). Geology of the lead mines and veins of Hampshire County, Massachusetts. Scale, 3 miles to an inch.

Accompanying "Notices of the lead mines and veins of Hampshire County, Massachusetts, and of the geology and mineralogy of that region." Amer. Jour. Silliman. Vol. XII, p. 270. New Haven, 1827.

200.

1833—**Hitchcock** (E.). A geological map of Massachusetts. Scale, 5 miles to three-quarters of an inch.

Accompanying "Report on the geology of Massachusetts under the direction of the government of that State." Amer. Jour. Silliman. Vol. XXII. New Haven, 1833.

Is also published separately.

201.

1833—**Hitchcock** (E.). A geological map of Massachusetts.

Accompanying "Report on the geology, mineralogy, &c., of Massachusetts, with an atlas in 4° of plates." Plate I. Amherst, 1853.

202.

1837—**Hitchcock** (E.). Geology of Portland and its vicinity.

Accompanying "Sketch of the geology of Portland and its vicinity," in Boston Journal of Natural History, Vol. I, p. 360. Boston, 1837.

The copy seen of this map has not been colored; there are merely a few black etchings on it.

203.

1840—**Jackson** (C. T.). A geological map of Rhode Island. Scale, 3 miles to an inch.

Accompanying "Report on the geological and agricultural survey of the State of Rhode Island." Providence, 1840.

204.

1841—**Hitchcock** (E.). A geological map of Massachusetts. Fourth edition.

Accompanying "Final report on the geology of Massachusetts," Vol. I, Plate 52. Frontispiece. 4°. Northampton, 1841.

The author calls it an "Index to a Geological Map of the State"; and adds: "Whenever the large map shall be completed, and the government wish, I shall be ready to color it geologically." The larger map was published in 1844, under the title, "Geological map of Massachusetts, made by order of the legislature." Scale, 5 miles to an inch, 1:316,800. It is placed at the left hand lower corner of the large topographical map published by the legislature. Boston, 1844.

205.

1842—**Percival** (J. G.). A geological map of Connecticut.

Accompanying "Report on the geology of the State of Connecticut." New Haven, 1842.

Black, with the outlines of the formations and letters.

206.

**1844—Hitchcock** (E.). Geological map of Massachusetts order of the legislature. Scale, 5 miles to an inch, or Boston, 1844.

It is placed at the left hand lower corner of the large topogr published by the legislature.

See **Hitchcock** (Edward), 1841—No. 204.

207.

**1844—Jackson** (C. T.). A geological map of New Hampshir 6 miles to the inch.

Accompanying "Final report on the geology and mineralogy of New Hampshire." 4°. Concord, 1844.

Black, with conventional signs only.

208.

**1845—Jackson** (C. T.). A geological map of New Hampshir 6 miles to the inch.

Accompanying "Views and map illustrating the scenery an the State of New Hampshire." Boston, 1845.

See **Jackson** (C. T.), 1844, same map—No. 207.

209.

**1853—Hitchcock** (E.). (Geological map.) Bristol and Rho coal field.

Accompanying "Report on certain points in the geology of Mas House (Document) No. 39, p. 4. Boston, 1853.

No place or date of publication on the map. It is the first ge printed mechanically in colors in America, by A. Sonrel, of Wob chusetts.

210.

**1857—Hitchcock** (E.). Ichno-geological map of the Connectic

Accompanying "A report on the sandstone of the Connect especially its fossil foot-marks." 4°. Plate II. Boston, 1858.

211.

**1857—Hitchcock** (E.). Ichno-geological map of the Connec ley (portion in Massachusetts).

Accompanying "Some indications of recent sensitiveness to un ures in the earth's crust." By H. F. Walling. Proceedings Association for the advancement of science. Vol. XXVII, p. 1879.

212.

**1860—Hager** (A. D.). Geological map of Plymouth, Vermon

Accompanying "Report on the geology of Vermont," in tw Vol. II, Plate XVIII. Claremont, N. H., 1861.

213.

1860—**Anonymous** (Hitchcock, C. H.). Road map of the island of Rhode Island or Aquidneck. Scale, 1 inch to the mile. Newport, (R. I.), 1860.

Presented by the city of Newport to the members of the American Association for the Advancement of Science August 1, 1860. Colored geologically.

214.

1861—**Hager** (A. D.). Geological map of the State of Vermont.

Accompanying "Map of the State of Vermont under the direction of H. F. Walling," in four sheets. A small map in the corner of the title sheet. New York, 1861.

215.

1861—**Hitchcock** (father and sons). Geological map of a part of Rutland County and Isle la Motte, Vermont.

Accompanying "Report on the Geology of Vermont," in two volumes, 4to, Vol. II, Plate VIII. Claremont, N. H., 1861.

216.

1861—**Hitchcock** (father and sons). Geological map of Vermont, traced out and compiled by the members of the geological survey, Messrs. Edward Hitchcock, Edward Hitchcock, jr., Charles H. Hitchcock, and Albert D. Hager. Scale, 1:400,000.

Accompanying "Report on the geology of Vermont," in two volumes, 4to, Vol. II. Claremont, N. H., 1861.

217.

1861—**Hitchcock** (C. H.). Map of the surface geology of Vermont. Scale, 1:400,000.

Accompanying "Report on the geology of Vermont," in two volumes, 4to, Vol. II. Claremont, N. H., 1861.

218.

1862—**Hitchcock** (C. H.). Geological map of Northern Maine.

Accompanying "Notes on the geology of Maine," in Proceed. of the Portland Society of Nat. Hist., Vol. I, Part I., p. 84. Portland, 1862.

Black etching and geological indications.

See **Hitchcock** (C. H.), 1862—No. 219.

219.

1862—**Hitchcock** (C. H.). Geological map of Northern Maine.

Accompanying "General report upon the geology of Maine," sixth annual report of the secretary of the Maine Board of Agriculture, p. 318. Augusta, 1861.

Black etching and geological indications. The report is dated 1861 and the map 1862.

220.

**1863—Hitchcock** (C. H.). (No title on the map.) Geological maj country between Belfast and Saint George, west side of scot Bay, Maine.

Accompanying "Second annual report upon the Nat. Hist. and G the State of Maine," Part II, p. 227. (Boston) 1863.

Black etching and colors. No name of place of publication, but t map was lithographed in Boston.

221.

**1863—Hitchcock** (C. H.). Geology of Rockport and vicinity.

Accompanying "Second annual report upon the Nat. Hist. and G the State of Maine," p. 242. (Boston) 1863.

Black etching.

222.

**1869—Hitchcock** (C. H.). Geological map of part of the Amm gold field, New Hampshire.

Accompanying "First annual report upon the geology and mine the State of New Hampshire." Manchester, 1869.

223.

**1870—Hitchcock** (C. H.). Map illustrating the distribution of gr New Hampshire.

Accompanying "Second annual report upon the geology and mi of the State of New Hampshire." Manchester, 1870.

224.

**1871—Hitchcock** (C. H.). Geological map of Massachusetts. S miles to an inch.

Accompanying "Official Topographical atlas of Massachusetts," Walling and O. W. Gray. Folio, p. 18. Boston, 1871.

225.

**1872—Hitchcock** (C. H.). (No title.) Geological map of the Mountains.

Accompanying "Report of the geological survey of the State of Ne shire," showing its progress during the year 1871. Nashua, 1872.

226.

**1874—Marcou** (Jules). Carte géologique des bords du Lac Ch entre Georgia (Vermont), Chazy (New York), et Phillip (Canada).

Accompanying "Sur les colonies dans les roches Taconiques des Lac Champlain," Bull. Soc. Géol. France," 3ième série, Vol. IX, p. 1 1880.

Scale, 1:160,000, is not given on the map, owing to a mistake o gravers.

227.

1877—**Crosby** (W. O.). Geological map of Eastern Massachusetts and of Boston and vicinity. Scale, 1 mile to the inch for Boston and 5 miles to 1 inch for Eastern Massachusetts.

Accompanying "Contributions to the geology of Eastern Massachusetts." Occasional papers of the Boston Society of Natural History, III. Boston, 1880.

These two maps are on the same large sheet. The smaller one (Eastern Massachusetts) occupying the right-hand lower corner.

228.

1877—**Hitchcock** (C. H.). Geological map of New Hampshire and Vermont.

Accompanying "A topographical atlas of New Hampshire," by Walling. (New York,) 1877.

229.

1877—**Hitchcock** (C. H.). Geological map illustrating the relation of the New Hampshire formations to those of the adjacent territory.

Accompanying "The geology of New Hampshire, Vol. II, p. 8. Plate I. Concord, 1877.

Black etching.

230.

1878—**Hitchcock** (C. H.). (No title.) Map of the Ammonoosuc mining district.

Accompanying the "Report on the geology of New Hampshire." Folio atlas. New York, 1878.

On the map itself no name of author, no date, and no place of publication are inscribed.

331.

1878—**Hitchcock** (C. H.). (No title.) General geological map of New Hampshire, embracing portions of Maine, Vermont, and Quebec. Scale, 2½ miles to the inch.

Accompanying the "Report on the geology of New Hampshire." Folio atlas. New York, 1878.

Six sheets. No title, no date, nor scale are inscribed on the map. The explanation is to be found in Vol. II, p. 672, of "Geology of New Hampshire."

232.

1881—**Hawes** (G. W.). Map of the Mount Willard region. Scale, 2½ miles to 1 inch.

Accompanying "The Albany granite, New Hampshire, and its contact phenomena," Amer. Journ. Silliman. 3d series, Vol. XXI, p. 22. New Haven, 1881.

Black etching.

## VIII.—NEW YORK AND NEW JERSEY.

233.

**1822—Barton** (D. W.). Barton on the Catskills.

Accompanying "Notice of the geology of the Catskills." Amer. Journ. Silliman. Vol. IV, p. 250. New Haven, 1822.

Black etching and geological indications.

234.

**1830—Eaton** (Amos). This colour'd map exhibits a general view of the economical geology of New York and part of the adjoining States.

Accompanying "Geological text-book prepared for popular lectures on North American geology with applications to agriculture and the arts." Albany, 1830.

This is the first attempt at a geological map of the State of New York.

235.

**1831—Young** (J. B.) and **Heron** (J.). Geological mineralogical map of a part of Orange County, New York. Scale, 2 miles to the inch.

Accompanying "Mineralogy and geology of the counties of Orange (N. Y), and Sussex (N. J.), by Charles U. Shepard. Amer. Journ. Silliman. Vol. XXI, p. 321. New Haven, 1832.

Black etching.

236.

**1839—Rogers** (H. D.). A geological map of New Jersey. Scale, 6 miles to one inch.

Accompanying "Description of the geology of the State of New Jersey, being a final report." Philadelphia, 1840.

237.

**1842—Emmons** (E.). Map of the county of Jefferson.

Accompanying "Geology of New York," Part II, comprising the survey of the second geological district. Plate XVI. 4°. Albany, 1842.

238.

**1842—Emmons** (E.). Geological map of Clinton County.

Accompanying "Geology of New York," Part II, comprising the survey of the second geological district. Plate XVII. 4°. Albany, 1842.

ıcy exists between the map and the volumes of explanation which show
t of harmony and a great difference of views between the geologists who
ıarge of the publication. In the volume Part IV we find in the "Tab-
iew of the sedimentary rocks of New York," and in the "Plan of ar-
nent in the State geological collection," the Taconic system, spelled also
onick; but no trace of it exists on the geological map. Emmons being
thor of the main part of the classification, and being convinced that a
ı of strata older than the Potsdam sandstone existed, maintained his
n the first volume of the "Agriculture of New York," where he describes
'aconic system." And in order to show the geographical distribution and
)n of these rocks, he prepared a geological map of the State of New York
Agriculture," part V, p. 361), a reprint, as he says, in the main of the
:hich accompanies the first reports (*i. e.*, the map published by legisla-
uthority referred to here). Important additions, however, were made
Parts of Vermont, Massachusetts, and Connecticut, were included; in
on to this, the Taconic system was marked out and colored and made a
:t part of the map; it occupies a belt extending from the Canadian line
w Jersey and Tappan Bay on the Hudson River below the Highlands.
three thousand copies of this modified map of the State, showing the
; of the Taconic in New York, were stolen or destroyed by persons un-
ı, so that they were never issued with the proper volume." (Extract
, letter of E. Emmons to J. Marcou, dated Raleigh, N. C., December 28,

240.

**er (W. W.). Geological map of Long and Staten Islands, the environs of New York..**

)mpanying "Geology of New York." Part I comprising the geology of
st geological district. .Plate I. 4°. Albany, 1843.

241.

**ns (S.). A geological map of New York or Manhattan Island.**

)mpanying "A geological history of Manhattan or New York Island."

243.

**1846—Lyell** (Sir Charles). Birds-eye view of the falls of Niagara and adjacent country, coloured geologically.

Accompanying "Reisen in Nord-Amerika von Charles Lyell." German edition. Halle, 1846.

See **Lyell** (*Sir* Charles), 1845—No, 242.

244.

**1855—Lyell** (Sir Charles). Birds-eye view of the falls of Niagara and adjacent country, coloured geologically.

Accompanying "Travels in North America in the years 1841–42." 2 vols Frontispiece of Vol I. 2d edition. London, 1855.

See **Lyell** (*Sir* Charles), 1845—242.

245.

**1865—Credner** (H.). Geologische Skizze von New York.

Accompanying "Geognostiche Skizze der Umgegend von New York." Zeitsch. Deut. Geol. Gesells. Vol. XVII, Taf. XIII. Berlin, 1865.

246.

**1865—Cook** (G. H.). Geological map of New Jersey.

Accompanying "Annual report of the geological survey of New Jersey for 1864." Trenton, 1865.

247.

**1868—Cook** (G. H.) and **Smock** (J. C.). Geological survey of New Jersey. Cretaceous formations: including the green-sand marl beds. Scale, 2 miles to an inch.

Accompanyihg "Geology of New Jersey," by authority of the legislature with a 4to atlas. Map, No. 3. Newark, 1868.

In two sheets.

248.

**1867—Cook** (G. H.) and **Smock** (J. C.). Geological survey of New Jersey. Map of Oxford furnace iron-ore veins. Scale, 8 inches per mile.

Accompanying "Geology of New Jersey," by authority of the legislature with a 4to atlas. Map No. 7. Newark, 1868.

249.

**1867—Cook** (G. H.) and **Smock** (J. C.). Geological survey of New Jersey. Map of zinc mines, Sussex County. Scale, 8 inches per mile.

Accompanying "Geology of New Jersey," by authority of the legislature with a 4to atlas. Map No. 8. Newark, 1868.

No explanation of the coloring on the map; there are mineralogical indications on the sections.

250.

**7—Cook** (G. H.) and **Smock** (J. C.). Geological survey of New Jersey. Triassic formation, including the red sandstone and trap rocks of Central New Jersey. Scale, 2 miles to an inch.

Accompanying "Geology of New Jersey," by authority of the legislature; with a 4to atlas. Map No. 2. Newark, 1868.

In two sheets.

251.

**7—Cook** (G. H.) and **Smock** (J. C.). Geological survey of New Jersey. Tertiary and recent formations of Southern New Jersey.

Accompanying "Geology of New Jersey," by authority of the legislature; with a 4to atlas. Map No. 4. Newark, 1868.

In two sheets; no scale is given, but it is evidently that of 2 miles to the inch.

252.

**8—Cook** (G. H.). No title. (A geological map of New Jersey.) Scale, 20 miles to an inch.

Accompanying "Geology of New Jersey," by authority of the legislature; p. 39 of the introduction. Newark, 1868.

Black etching.

253.

**8—Cook** (G. H.) and **Smock** (J. C.). Geological survey of New Jersey. Azoic and paleozoic formations, including the iron-ore and limestone districts. Scale, 2 miles to an inch.

Accompanying "Geology of New Jersey," by authority of the legislature; with a 4to atlas. Map No. 1. Newark, 1868.

In two sheets.

254.

**0—Credner** (H.). Geognostische Skisse von New Jersey nach Rogers, Cook, and Smock.

Accompanying "Die Kreide von New Jersey." Zeitsch. Deut. Geol. Gesells. Vol. XXII, Taf. IV. Berlin, 1870.

Black etching and geological indications.

255.

**0—Cook** (G. H.). Lake Passaic (a glacial lake). Scale, 6 miles to the inch.

Accompanying "Annual report of the State geologist for the year 1880." Trenton, 1880.

256.

**80—Cook** (G. H.) and **Smock** (J. C.). The State of New Jersey. Economic geology. Scale, 6 miles to the inch.

Accompanying "Annual report of the State geologist for the year 1879." Trenton, 1879.

257.

**1880—Dana** (J. D.). Part of Western Cortlandt.

Accompanying "Geological relations of the limestone belts of Weste County, New York." Amer. Journ. Silliman, 3d series, Vol. XX, New Haven, 1880.

Black etching.

258.

**1880—Dana** (J. D.). Limestone areas of Westchester County. 3 miles to the inch.

Accompanying "Geological relations of the limestone belts of West County, New York." Amer. Journ. Silliman, 3d series, Vol. XX, P New Haven, 1880.

In one color and black etching.

259.

**1880—Dana** (J. D.). Geological map of part of New York an Jersey, from Prof. G. H. Cook's map of New Jersey. Sc miles to the inch.

Accompanying "Geological relations of the limestone belts of Wes County, New York." Amer. Journ. Silliman, 3d series, Vol. XX, P New Haven, 1880.

Black etching.

260.

**1880—Dana** (J. D.). Limestone areas of Dutchess, Westcheste Putnam Counties, New York, and of part of Western Conne with the Archæan of Putnam County, and the Palisad range. Scale, 10 miles to the inch.

Accompanying "Geological relations of the limestone belts of Wes County, New York." Amer. Journ. Silliman, 3d series, Vol. XX, Pla New Haven, 1880.

Black etching.

261.

**1881—Abbott** (C. C.). Map of area of Trenton gravel in vici Trenton, N. J.

Accompanying "Primitive industry; or illustrations of the hand stone, bone, and clay of the native races of the Northern Atlantic sea America." p. 531. Salem, 1881.

262.

**1881—Britton** (N. L.). A geological map of Richmond Count York. Scale, 1:120,000.

Accompanying "On the geology of Richmond County, New York. New York Acad. Sci., Vol. II. Plate XV, p. 161. New York, 1881.

263.

**1881—Cook** (G. H.) and **Smock** (J. C.). Geological map of New Scale, 6 miles to 1 inch.

Accompanying "Geological Survey of New Jersey." Annual repo State Geologist for the year 1881. Trenton, 1881.

A well-executed and clear geological map.

264.

1—**Dana** (J. D.). Geological map of southern Westchester County and northern New York island. Scale, 2 inches to 1 mile.

Accompanying "Geological relations of the limestone belts of Westchester County, New York." Amer. Journ. Silliman, 3d series, Vol. XXI, Plate XIX. New Haven, 1881.

In one color, and geological indications.

265.

81—**Dana** (J. D.). Part of Western Cortlandt.

Accompanying "On a case in which various massive crystalline rocks, including soda-granite, quartz-diorite, norite, hornblendite, pyroxenite, and different chrysolitic rocks, were made through metamorphic agencies in one metamorphic process. The Geological Magazine, 2d series, Vol. VIII, p. 60. London, 1881.

Black etching.

266.

1881—**Dana** (J. D.). Stony Point.

Accompanying "Geological relations of the limestone belts of Westchester County, New York. Origin of the rocks of the Cortlandt series." Amer. Journ. Silliman, 3d series, Vol. XXII, p. 112. New Haven, 1881.

Black, with geological indications.

267.

1881—**Dana** (J. D.). Map of parts of New York and New Jersey. Scale, 10 miles to 1 inch.

Accompanying "Geological relations of the limestone belts of Westchester County, New York. Origin of the rocks of the Cortlandt series." Amer. Journ. Silliman, 3d series, Vol. XXII, p. 106. New Haven, 1881.

Black etching.

268.

881—**Dana** (J. D.). Map of part of western Cortlandt, showing the Peekskill, Verplanck, Tompkins, Cove, and Cruger limestone areas, by horizontal lining. Scale, 1 inch to a mile.

Accompanying "Geological relations of the limestone belts of Westchester County, New York. Origin of the rocks of the Cortlandt series." Amer. Journ. Silliman, 3d series, Vol. XXII, p. 107. New Haven, 1881.

Black etching.

All these small maps by Mr. J. D. Dana are sketch-maps with geological indications.

269.

**1822—Cist** (Z.). Range of the anthracite formation of Pennsylvania.

Accompanying "Account of the mines of anthracite in the region abo Wilkesbarre, Pennsylvania." Amer. Journ. Silliman, Vol. IV, p. 14. Ne Haven, 1822.

Black etching.

270.

**1824—Finch** (J.). Geology of Easton, &c.

Accompanying "A sketch of the geology of the country near Easto Pennsylvania." Amer. Journ. Silliman, Vol. VIII. New Haven, 1824.

271.

**1826—Troost** (Gerard). Karte der Gegend von Philadelphia.

Accompanying "Geological survey of the environs of Philadelphia," cit by B. Cotta, in his "Geognostische Karten unseres Jahrhundert's," 1850, p. 4 No. 533. This map is unknown even in Philadelphia, and contemporari of Troost, such as the late T. Conrad and Mr. Isaac Lea, had never heard of suc a map. It is very doubtful if it exists.

272.

**1834—Taylor** (R. C.). Rough sketch of the position of the transitio beds near Lewiston, Mifflin County, Pennsylvania, containin various species of fossil Fucoides. Scale, 1 inch to 1 mile.

Accompanying "On the geological position of certain beds which conta numerous fossil marine plants of the family Fucoides, near Lewiston, Miffli County, Pennsylvania," in Transactions of the Geological Society of Pennsy vania, Vol. I, Part I, Plate IV. Philadelphia, 1834.

[redacted]3.

**1835—Koehler** (H.). Petrographical map of the coal region of Tamaqua

Accompanying "On the anthracite deposit at Tamaqua, Schuylkill County Pennsylvania." Transactions of the Geological Society of Pennsylvania, Vol I, Part II, p. 326. Philadelphia, 1835.

Black etching and geological indications.

274.

**1835—Taylor** (R. C.). Map of Kishacoquillas Valley. Scale, 5 miles t an inch.

Accompanying "Notice as to the evidences of the existence of an ancien lake, which appears to have formerly filled the limestone valley of Kisha coquillas, in Mifflen County, Pennsylvania." Transactions of the Geologica Society of Pennsylvania, Vol. I, Part II, p. 198. Philadelphia, 1835.

275.

**1848—Taylor** (R. C.). Map of the group of anthracite basins in Pennsylvania.

Accompanying "Statistics of coal," p. 112. Philadelphia, 1848.

276.

**1848—Taylor** (R. C.). Map illustrative of the statistics of the coal trade of Pennsylvania. Showing the relative positions of the various anthracite and bituminous coal fields.

Accompanying "Statistics of coal," p. 144. Philadelphia, 1848.

277.

**1857—Dalson** (A. F.). Geological map of the Howard Hill coal field. Scale, 1 mile to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania. The geology of McKean County," by Chas. A. Ashburner. Vol. R, p. 168. Harrisburg, 1880.

278.

**1857—Rogers** (H. D.). Map of the anthracite and bituminous coal fields of Pennsylvania.

Accompanying "The geology of Pennsylvania." 4°. Vol. II, p. 1019. Edinburg, 1858.

Black etching.

279.

**1858—Rogers** (H. D.). Map of the mining district of Chester and Montgomery Counties.

Accompanying "The geology of Pennsylvania." 4°. Vol. II, Part III, p. 674. Edinburg, 1858.

280.

**1858—Rogers** (H. D.). Map of the Cornwall ore hills, Lebanon County.

Accompanying "The geology of Pennsylvania." 4°. Vol. II, Part IV, p. 719. Edinburg, 1858.

Black etching with geological indications.

281.

**1858—Rogers** (H. D.). Geological and topographical map of the anthracite fields of Pennsylvania. Scale, 2 miles to the inch.

Accompanying "The final report on the geological survey of the State 1858." 4°. Atlas. Edinburg, 1858.

In two sheets.

282.

**1858—Rogers** (H. D.). Geological map of the State of Pennsylvania, constructed from original surveys made between the years 1836 and 1857. Scale, 5 miles to the inch.

Accompanying "The final report on the geological survey of the State, 1858." 4°. Atlas. Edinburg, 1858.

In three sheets.

283.

**1859—Tyson** (P. T.). Geological illustrations (preliminary geo map of Maryland).

Accompanying "First report of Philip T. Tyson, State agricultural to the house of delegates of Maryland." Annapolis, 1860.

284.

**1864—Great** (W., jr.). Map of the Lackawanna coal field, I County, Pennsylvania.

Accompanying "Notes on the anthracite coal region of North A Trans. North of England Inst. Mining Engrs. Vol. XIII, p. 25. Ne upon-Tyne, 1864.

285.

**1864—Lesley** (J. P.). (No title.)

Accompanying "On the discovery of lignite in Pennsylvania." Pro Phil. Soc., Vol. IX, Plate XI. Philadelphia, 1865.

Colored and with geological indications.

286.

**1871—Lesley** (J. P.). A map showing the topographical char the southern part of the lands of the Pittsburgh and Ba coal, coke, and iron company, Ursina, in Somerset County sylvania. Scale of 1 mile (to the inch?)

Accompanying "Note on an apparent violation of the law of reg gressive debituminization of the American coal beds coming East. Amer. Phil. Soc., Vol. XII, p. 131. Philadelphia, 1873.

Black, with indications of limestone and ferriferous coal bed banks on it.

287.

**1871—Platt** (Franklin, jr.). Map of the Pittsburgh and Baltimo coke, and iron company's lands, Ursina, Somerset County sylvania. Scale, 1,500 feet to an inch.

Accompanying "Note on an apparent violation of the law of reg gressive debituminization of the American coal beds coming East. Amer. Phil. Soc., Vol. XII, p. 160. Philadelphia, 1873.

A topographical map, with lithological and mineralogical indicatic ten on the map.

288.

**1871—Lesley** (J. P.). A map showing the areas occupied by th coal bed in the hills north of Ursina. Scale, 1 mile to t

Accompanying "Note on apparent violation of the law of regular pr debituminization of the American coal beds coming East." Proc. Am Soc., Vol. XII, p. 129. Philadelphia, 1873.

Black etching.

289.

1872—**Lesley** (J. P.). (No title.) Scale, 1 inch to 1 mile.

Accompanying "Saint Clairsville and Bedford Railroad, and Dunning's Creek fossil iron ore." Proc. Amer. Phil. Soc., Vol. XIII, p. 256. Philadelphia, 1873.

In one color and geological indications.

290.

1872—**Smith** (S.). Topographical map of Gaines Coal Basin, in Gaines Township, Tioga County. Contour curves, 100 feet apart. Scale, 2,000 feet to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress, vol. G. G. G., by Andrew Sherwood. Harrisburg, 1880.

Black etching.

291.

1872—**Strauch** and **Cochran**. Map of the first and second anthracite coal fields of Pennsylvania.

Accompanying "Coal regions of America," by James Macfarlane. p. 17. New York, 1873.

Black etching.

292.

1873—**Lesley** (J. P.). Topographical map of Pennsylvania, colored for the principal geological formations.

Accompanying "Coal regions of America," by James Macfarlane. New York, 1873.

293.

1873—**Lesley** (J. P.). A study, in ten-foot contour-lines, of the structure and erosion of Brush Mountain, showing the outcrops of the two upper silurian fossil iron ore beds passing Tyrone Gap, Blair County, Pennsylvania.

Accompanying "A study of the structure and erosion of Brush Mountain." Proc. Amer. Phil. Soc., Vol. XIII. Philadelphia, 1873.

Black, with geological indications.

294.

1874—**Clark** (E., jr.). A map in ten-foot contour lines, showing the ranges of brown hematite ore banks in a portion of Lehigh County. Scale, 3,200 feet to the inch.

Accompanying "2d Geol. Surv. Pennsylvania. Brown hematite ore ranges of Lehigh County," by Frederick Prime, jr. Vol. D. Harrisburg, 1875.

Black etching, with geological indications. See note by State geologist, page 67.

295.

1874—**Frazer** (P., jr.) and **Lehman** (A. E.). A map of the central belt of brown hematite ore mines in York and Adams Counties. Scale, 1 mile to the inch.

Accompanying "2d Geol. Surv. Pennsylvania. Report of progress in York and Adams Counties," by Persifor Frazer. Vol. C, p. 196. Harrisburg, 1876.

296.

**1874—Lesley** (J. P.) and **Platt** (F.). A study, in twenty-foot contour lines, of the structure and erosion of a part of the lower silurian iron ore region northeast of the Little Juniata River, in Huntingdon and Centre Counties, Pennsylvania. Scale, before reduction by photograph, 3.325 inches to 1 mile.

Accompanying "The brown hematite ore banks of Spruce Creek, Warrior's Mark Run, and Half Moon Run, in Huntingdon and Centre Counties, Pennsylvania, along the line of the Lewisburg, Centre County, and Tyrone Railroad." Proc. Amer. Phil. Soc., Vol. XIV, p. 176. Philadelphia, 1876.

Black, with geological indications.

297.

**1875—Wrigley** (H. E.). Map B, the Pennsylvania oil regions proper, with all adjoining developments in Ohio, New York and West Virginia.

Accompanying "2d Geol. Surv. Pennsylvania." Special report on the petroleum of Pennsylvania, by Henry E. Wrigley, Vol. J. Harrisburg, 1875.

Black etching.

298.

**1875—Frazer** (P., jr.) and **Lehman** (A. E.). General map of the ore ranges of York and Adams Counties. Scale, 3 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in York and Adams Counties, by Persifor Frazer. Vol. C, p. 64. Harrisburg, 1876.

299.

**1876—Boyd** (E. F.). Map of the first and second anthracite coal fields of Pennsylvania.

Accompanying "Remarks on the coal measures and oil produce of the United States of America, collected during a visit to that country in the autumn of 1875." Trans. North of England Inst. Mining Engrs., Vol. XXV, Plate XLIV. Newcastle-upon-Tyne, 1876.

300.

**1876—Boyd** (E. F.). Map showing the anthracite coal fields of Pennsylvania with their outlets to tide-water.

Accompanying "Remarks on the coal measures and oil produce of the United States of America, collected during a visit to that country in the autumn 1875." Trans. North of England Inst. Mining Engrs., Vol. XXV, Plate XL Newcastle-upon-Tyne, 1876.

Black etching.

301.

**1876—Boyd** (E. F.). Map of the anthracite coal fields of Pennsylvania

Accompanying "Remarks on the coal measures and oil produce of the United States of America, collected during a visit to that country in the autumn 1875." Trans. North of England Inst. Mining Engrs., Vol. XXV, Plate XL Newcastle-upon-Tyne, 1876.

302.

**6—Boyd** (E. F.). Oil regions of Pennsylvania, U. S.

Accompanying "Remarks on the coal measures and oil produce of the United States of America, collected during a visit to that country in the autumn of 1875." Trans. North of England Inst. Mining Engrs., Vol. XXV, Plate XLIX. Newcastle-upon-Tyne, 1876.

Black, with geological indications.

303.

**'6—Lesley** (J. P.) and **White** (I. C.). Map of southern Butler, showing outcrops of the lower coals. Scale, 2 miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in the Beaver River district, by I. C. White. Vol. Q. Harrisburg, 1878.

304.

**'6—Lesley** (J. P.) and **White** (I. C.). Map of North Allegheny, showing outcrops of the Pittsburgh and upper Freeport coals. Scale, 2 miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in the Beaver River district, by I. C. White. Vol. Q. Harrisburg, 1878.

305.

**'6—Lesley** (J. P.) and **White** (I. C.). Map of Beaver County, showing outcrops of the Pittsburgh, Upper Freeport, and Kittanning coals. Scale, 2 miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in the Beaver River district, by I. C. White. Vol. Q. Harrisburg, 1878.

306.

**'6—Lesley** (J. P.) and **Sherwood** (A.). Geological map of Potter County. Scale, 2 miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of Potter County, by Andrew Sherwood. Vol. GGG, Harrisburg, 1880.

307.

**'6—Lesley** (J. P.) and **Sherwood** (A.). Geological map of Wyoming County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of Pike and Monroe Counties, by I. C. White. Report of progress. Vol. G 6. Harrisburg, 1882.

In the same volume G 6 there is a large geological map of Pike and Monroe Counties, with the date of 1882 on the map, and consequently posterior to the limit of this catalogue. 1881.

308.

**'6—Prime** (Fred.). Geological and topographical map showing the limestone of Lehigh County including the ranges of brown hematite ore banks.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress, 1875, '76. Lehigh district. Vol. DD. Harrisburg, 1878.

In four sheets.

309.

**1876—Schellenberg** (F. Z.). Map showing outcrops of Pittsbu in North Huntingdon Township, Westmoreland County,

Accompanying "2d Geol. Surv. Pennsylvania." Report of progr Fayette and Westmoreland districts, by J. J. Stevenson. Vol. KI Harrisburg, 1877.

Black etching.

310.

**1876—Sherwood** (A.). Geological map of Bradford County. miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progres ford and Tioga Counties. Vol. G. Harrisburg (1878).

No date on the volume.

311.

**1876—Sherwood** (A.). Geological map of Tioga County. Scale to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progres ford and Tioga Counties. Vol. G. Harrisburg (1878).

No date on the volume.

312.

**1876—Stevenson** (J. J.) and **White** (I. C.). Geological map of Al County.

Accompanying "2d Geol. Surv. Pennsylvania." Report of prog Fayette and Westmoreland district. Vol. KK. Harrisburg, 1877.

313.

**1877—Lesley** (J. P.) and **Platt** (F.). A geological map of the S central coal basin in Somerset County, Pa.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progr HHH. Harrisburg, 1877.

Black, without truly any geological indications or signs.

314.

**1877—Stevenson** (J. J.). Geological map of Fayette County Chestnut Ridge. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of prog Fayette and Westmoreland district. Vol. KK. Harrisburg, 1877.

315.

**1877—Stevenson** (J. J.). Geological map of Westmoreland Cou of Chestnut Ridge. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of prog Fayette and Westmoreland district. Vol. KK. Harrisburg, 1877.

316.

8—**Ashburner** (C. A.). Isometric projection to illustrate the direction and amount of throw along the plan of the fault at Three Springs, Huntingdon County. Scale, 800 feet to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in the Juniata district. Vol. F. Plate XVIII. Harrisburg, 1878.

Black, with geological indications.

317.

'8—**Ashburner** (C. A.). Geological map of a belt of country lying along the line of the East Broad Top Railroad, from the crest of Sideling Hill across Smith's, Hare's, and Great Aughwick Valleys to the crest of Black Log Mountain, Huntingdon County. Scale, 1,600 feet to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in the Juniata district. Vol. F. Plate I. Harrisburg, 1878.

318.

78—**Ashburner** (C. A.). Geological map of the environs of Orbisonia, at Rockhill Gap, Huntingdon County, showing the outcrops of the Clinton, Oriskany, and Marcellus iron beds.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in the Juniata district. Vol. F. Plate II. Harrisburg, 1878.

319.

8—**Ashburner** (C. A.). Geological section passing near Three Springs, Huntingdon County, constructed from exposures on and near the line of the East Broad Top Railroad, showing the order of the Devonian and Silurian strata from Plank Cabin Valley to Black Log Mountain. Scale, 1,600 feet to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in the Juniata district. Vol. F. Plate XVI. Harrisburg, 1878.

In two sheets. This section is accompanied by fragments of geological maps.

320.

—**Ashburner** (C. A.) Geological section of Devonian and Silurian strata exposed along Sideling Hill Creek, extending from the East Broad Top coal basin, Huntingdon County, to the crest of Black Log Mountain, at Potts Gap, Fulton County. Scale, 1,600 feet to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in the Juniata district. Vol. F. Plate XVII. Harrisburg, 1878.

In two sheets. This section is accompanied by fragments of geological maps.

321.

—**Frazer** (P., jr.). Geological map of Lancaster County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in 1877; the geology of Lancaster County. Vol. CCC. Harrisburg, 1880.

322.

**1878—Lesley** (J. P.) and **White** (I. C.). Geological map of Law County. Scale, 2 miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of La County, by I. C. White. Vol. QQ. Harrisburg, 1878.

323.

**1878—Lesley** (J. P.) and **Frazer** (P., jr.). Geological map of Lan County. Scale, 2 miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." Vol. CCC. Atlas. burg, 1879.

324.

**1878—Lesley** (J. P.) and **Platt** (W. G.). Geological map of In County. Scale, 2 miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of prog Indiana County, by W. G. Platt. Vol. H4. Harrisburg, 1878.

325.

**1878—Prime** (Fred.). Map of the iron-ore mines at Ironton, I County. Scale, 300 feet for 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of p 1875–'76, Lehigh district. Vol. DD. Harrisburg, 1878.

326.

**1878—Stevenson** (J. J.). Geological map of Westmoreland C Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progres Ligonier Valley, by J. J. Stevenson. Vol. KKK. Harrisburg, 1878.

327.

**1878—Stevenson** (J. J.). Geological map of Washington C Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progres Ligonier Valley. Vol. KKK. Harrisburg, 1878.

328.

**1878—Stevenson** (J. J.). Geological map of Fayette County. S miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progre Ligonier Valley. Vol. KKK. Harrisburg, 1878.

329.

**1878—Stevenson** (J. J.). Geological map of Green County, with of the Pittsburgh and Waynesburg coal at various loc Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progres Ligonier Valley. Vol. KKK. Harrisburg, 1878.

330.

1879—**Ashburner** (C. A.) and **Sheafer** (A. W.). A geological map of McKean County, and a map of a portion of Cattaraugus County, New York. Scale, 1½ miles to 1 inch, or $\frac{1}{95040}$.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of McKean County, by Chas. A. Ashburner. Atlas R, Plate X. Harrisburg, 1880.

331.

1879—**Burlingame** (E. H.). A topographical map of part of the Little Pine Creek coal basin in Pine Township, Lycoming County. Contour curves 10 feet apart. Scale, 1,600 feet to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress, geology of Lycoming County, by Franklin Platt. Vol. GG. Harrisburg, 1880.

This map, in two sheets, is in black etching and in one color, with geological indications, and is published by permission of the author.

332.

1879—**Carll** (J. F.) and **Chance** (H. M.). Geological map of Venango County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties. Oil region maps and charts. Vol. III. Plate 20. Harrisburg, 1880.

333.

1879—**Chance** (H. M.). Geological map of Clinton County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress, Clinton County. Vol. G4. Harrisburg, 1880.

334.

1879—**Chance** (H. M.). Geological map of Clarion County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of Clarion County, by H. Martyn Chance. VV, Plate II. Harrisburg, 1880.

335.

1879—**Frazer** (P., jr.). Geological map of York County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in 1877. Vol. CCC. Harrisburg, 1880.

336.

1879—**Lesley** (J. P.) and **Ashburner** (C. A.). Topographical map of the Alton coal basin. Scale, 3,200 feet to the inch. Contour lines, 100′.

Accompanying "2d Geol. Surv. Pennsylvania." McKean County. Vol. R. Atlas. Harrisburg, 1879.

Coloured geologically.

337.

**1879—Lesley** (J. P.) and **Chance** (H. M.). Geological map of northern Butler. Scale, 2 miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." The northern townships of Butler County, by H. Martyn Chance. Vol. V. Harrisburg, 1879.

338.

**1879—Lesley** (J. P.) and **Chance** (H. M.). Map of instrumental survey of the valleys of the Beaver and Shenango Rivers and Slippery Rock Creek. Scale, 8,000 feet to 1 inch.

Accompanying "2d Geo. Surv. Pennsylvania." The northern townships of Butler County, by H. Martyn Chance. Vol. V. Harrisburg, 1879.

339.

**1879—Lesley** (J. P.) and **Chance** (H. M.). A map in 24 contour lines o the Allegheny Valley near Parker, in Armstrong and Butle Counties. Scale, 1.200=1 inch.

Accompanying "2d Geo. Surv. Pennsylvania." The northern townshi of Butler County, by H. Martyn Chance. Vol. V. Harrisburg, 1879.

Black etching.

340.

**1879—Lesley** (J. P.) and **White** (I. C.). Geological map of Mer County. Scale, 2 miles to the inch.

Accompanying "2d Geo. Surv. Pennsylvania." The geology of Mer County, by I. C. White. Vol. QQQ. Harrisburg, 1880.

341.

**1879—Lesley** (J. P.) and **Frazer** (P. jr.). Geological map of Y County. Scale, 2 miles to the inch.

Accompanying "2d Geo. Surv. Pennsylvania." Vol. CCC. Atlas. Har burg, 1879.

342.

**1879—Sherwood** (A.). Geological map of Lycoming County. Scale miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of L coming and Sullivan counties. Field notes, by Andrew Sherwood. C basins, by Franklin Platt. Vol. GG. Harrisburg, 1880.

343.

**1879—Sherwood** (A.). Geological map of Sullivan County. Scale, miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress Sullivan County, by Franklin Platt. Vol. GG. Harrisburg, 1880.

Field notes, by Andrew Sherwood. Coal basins, by Franklin Platt.

344.

**[0]—Platt** (W. G.). Geological map of Armstrong County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in Armstrong County. Vol. H5. Harrisburg, 1880.

345.

**80—Platt** (W. G.). Geological map of Jefferson County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Report of progress in Jefferson County. Vol. H6. Harrisburg, 1881.

346.

**80—White** (I. C.). Geological map of Crawford and Erie Counties. Scale, 2 miles to the inch.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of Erie and and Crawford Counties, by I. C. White. Vol. Q. Harrisburg, 1881.

In two sheets.

347.

**1—Ashburner** (C. A.). Map of part of the Mahanoy and Shenandoah basins in the second anthracite coal fields, showing the shape of the floor of the mammoth bed by contour lines 50 feet apart, and the area of the bed worked out and under development. Scale, 1,000 feet to 1 inch, 12 meters to 1 milimeter $\frac{1}{12000}$ of nature.

Accompanying "New method of mapping the anthracite coal fields of Pennsylvania." Trans. Amer. Inst. Mining Engrs., Vol. IX, Ashburner, Plate I, p. 516. Easton, Pa., 1881.

In colored etching and geological indications, it is essentially the same as the map in "2d Geol. Surv. Pennsylvania," Vol. A 2, by Ashburner, C. A., and Sheafer, A. W., 1881—No. 348.

348.

**1—Ashburner** (C. A.) and **Sheafer** (A. W.). Map of part of the Mahanoy and Shenandoah basins in the second anthracite coal field. Scale, 800 feet to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." A special report upon the causes, kinds, and amount of waste in mining anthracite, by Franklin Platt. Vol. A 2. Harrisburg, 1881.

In colored etching and geological indications. This map also appeared in Trans. Amer. Inst. Mining Engrs., Vol. IX, p. 516—No. 347.

349.

**[1]—Harden** (E. B.). Geological model of part of Blair, Bedford, and Huntingdon Counties, Pennsylvania. Scale, 5 miles to the inch.

Accompanying "Proc. Amer. Phil. Soc.," Vol. XIX, No. 109. Philadelphia, 1881.

In black, with numbers corresponding to colours; apparently a phototype.

350.

1881—**Platt** (F.). Topographical and geological map of that Blair, Bedford, and Huntingdon Counties, south of th Juniata River, between Tussey and Alleghany Mounta cluding Morrison's Cove, Canoe, Sinking, and Scotch Scale, 1,600 feet to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Blair atlas, T. Ha 1881.

In fourteen sheets.

351.

1881—**Platt** (F.). Index to the topographical and geological that part of Blair, Bedford, and Huntingdon Counties, the Little Juniata River, between Tussey and Alleghany ains, including Morrison's Cove, Canoe, Sinking, and Valleys. Scale, 8,000 feet to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Blair atlas, T. Ha 1881.

352.

1881—**White** (I. C.). Geological map of Susquehanna and Counties, and a part of Lackawanna County.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of hanna and Wayne County, by I. C. White, Vol. G 5. Harrisburg, 188

## X.—OHIO, INDIANA, AND MICHIGAN.

353.

1836—**Hildreth** (S. P.). A topographical and geological map of the coal measures, and of the muriatiferous and ferruginous deposits in the secondary region of the valley of the Ohio.

Accompanying "Observations on the bituminous coal deposits of the valley of the Ohio and the accompanying rock strata." Amer. Journ. Silliman, Vol. XXIX. New Haven, 1836.

Black etching, and with geological indications.

354.

1838—**Locke** (John). Geological map of Adams County, Ohio.

Accompanying "Second annual report on the geological survey of the State of Ohio," p. 238. Columbus, 1838.

Black, with geological indications.

355.

1844—**Locke** (John). Geological and magnetical chart of Copper Harbor (Lake Superior). Scale, $2\frac{3}{4}$ inches to a mile.

Accompanying "Observations made in the years 1838, '39, '40, '41, '42, and '43, to determine the magnetical dip, etc." Trans. Amer. Phil. Soc. New series. 4°. Vol. IX, Article XI, Plate XLV. Philadelphia, 1846.

Black etching, and geological indications.

356.

1845—**Burt** (W. A.). Geological map of township lines in the northern peninsula of Michigan.

Accompanying "Geological report." Message from the President of the United States, Part III, p. 811. Washington, 1849.

Black, with lithological indications.

357.

1845—**Houghton** (Douglass). Geological map of townships in the northern peninsula of Michigan.

Accompanying "Geological report." Message from the President of the United States, Part III, p. 880. Washington, 1849.

Black, with lithological indications.

358.

1845—**Burt** (W. A.). Geological map of a district of township lines in the northern peninsula of Michigan.

Accompanying "Geological report." Message from the President of the United States, Part III, p. 811. Washington, 1849.

Black, with lithological indications.

359.

**1846—Higgins** (S. W.) and **Hubbard** (Bela). Geological map trict E. and W. of the Ontonagon (Lake Superior).

Accompanying "Geological report." Message from the Presid United States, Part III, p. 833. Washington, 1849.

Black, with lithological indications.

360.

**1846—Hubbard and Ives.** Geological map of the district subdi Messrs. Hubbard and Ives.

Accompanying "Geological report of Bela Hubbard." Messag President of the United States, Part III, p. 882. Washington, 1849.

A map of the district between L'Anse and Granite Point, Lake S In black, with lithological indications.

361.

**1848—Whittlesey** (Charles). Outline map of the geological f of Ohio.

Accompanying "Outline sketch of the geology of Ohio," in Howe's Collections, p. 579. (Cleveland), 1848.

Black etching, with geological indications. Reprinted in 1856.

362.

**1848—Jackson** (C. T.). Geological map of Keweenaw Point, perior.

Accompanying "Report on the geological survey of the mineral l United States in the State of Michigan." Message from the Presi United States. Part III. Washington, 1849.

363.

**1849—Jackson** (C. T.). Geological map of Isle Royale, Lake S

Accompanying "Report on the geological survey of the miner the United States in the State of Michigan." Message from the P the United States. Part III. Washington, 1849.

364.

**1850—Foster** (J. W.) and **Whitney** (J. D.). Geological map of K Point, Lake Superior, Michigan; assisted by S. W. Hil Schlatter.

Accompanying "Report on the geology and topography of a por Lake Superior land district in the State of Michigan." Part I. Co Washington, 1850.

365.

**1850—Foster** (J. W.) and **Whitney** (J. D.). Geological ma Royale, Lake Superior, Michigan; assisted by S. W. Hil Schlatter.

Accompanying "Report on the geology and topography of a por Lake Superior land district in the State of Michigan." Part I. Co Washington, 1850.

366.

1850—**Foster** (J. W.) and **Whitney** (J. D.). Geological map of the district between Portage Lake and Montreal River, Lake Superior, Michigan; assisted by S. W. Hill and W. Schlatter.

Accompanying "Report on the geology and topography of a portion of the Lake Superior land district in the State of Michigan." Part I. Copper lands. Washington, 1850.

367.

1851—**Foster** (J. W.) and **Whitney** (J. D.). Geological map of the Lake Superior land district in the State of Michigan.

Accompanying "Report on the geology of the Lake Superior land district." Part II. The iron region, together with the general geology. Washington, 1851.

368.

1851—Anonymous (**Foster** (J. W.) and **Whitney** (J. D.)). Section and diagram illustrating the geology of the region between the northern shores of Lakes Superior and Michigan.

Accompanying "Report on the geology of the Lake Superior land district." Part II. The iron region, together with the general geology. Washington, 1851.

No name of authors on the map, but certainly by Foster and Whitney.

369.

1851—**Foster** (J. W.) and **Whitney** (J. D.). Geological map of the district between Keweenaw Bay and Chocolate River, Lake Superior, Michigan.

Accompanying "Report on the geology of the Lake Superior land district." Part II. The iron region, together with the general geology. Washington, 1851.

370.

1851—**Koch** (F. C. L.). Geognostische Karte der Mineral-Regionen am Lake Superior, Michigan, North Amer.

Accompanying "Die Mineral-Regionen der obern Halbinsel Michigan's (N. A.) am Lake Superior und die Isle Royal. Göttingen, 1852.

371.

1853—**Whitney** (J. D.). Geological map of Keweenaw Point, Lake Superior, Michigan. folio. New York, 1853.

Mr. Whitney was assisted by S. W. Hill and W. S. Stephens.

372.

1855—**Rivot** (L. E.). Carte géologique du Lac Supérieur, État de Michigan, dressée par MM. J. W. Foster et J. D. Whitney.

Accompanying "Voyage au Lac Supérieur." Annales des mines, 5e série, tome VII, p. 173, pl. VI. Paris, 1855.

Also issued separately.

373.

**1855—Rivot** (L. E.). Cartes de l'île Royale, de la Pointe de Keweenaw et de l'Ontonagon, dressées par MM. Foster et Whitney.

Accompanying "Voyage au Lac Supérieur." Paris, 1855.

374.

**1856—Newberry** (J. S.). Map of the A. and N. L. R. R., its connections and geology. (Ohio.)

Accompanying "Report on the economical geology of the route of the Ashtabula and New Lisbon Railroad." Cleveland, 1857.

Black etching and geological indications.

375.

**1856—Whittlesey** (Charles). Outline map of the geological formation of Ohio.

Accompanying "Outline sketch of the geology of Ohio; in outlines of the geology of Ohio," p. 579. Cleveland, 1856.

Black etching, with geological indications. Reprint of the map of 1848.

See **Whittlesey** (Charles), 1848—No. 361.

376.

**1856—Whittlesey** (Charles). Geological railroad and township map of the State of Ohio. Geological outlines by Charles Whittlesey. Scale, 12 miles to the inch.

Accompanying "Outlines of the geology of Ohio." Cleveland, 1856.

Reprinted in 1873 to compare with a reprint of J. S. Newberry's map of Ohio of 1867, in "Paleontology and the moral sense," by C. Whittlesey.

377.

**1865—Sayler** (N.). Geological map of Ohio. Scale, 5 miles to the inch. Cincinnati, Ohio, 1865.

Unseen.

378.

**1865—Sayler** (N.) Geological map of Indiana. Scale, 5 miles to the inch. Cincinnati, Ohio, 1865.

Unseen.

379.

**1865—Winchell** (Alexander). Map of the Grand Traverse region (Michigan).

Accompanying "A report on the geological and industrial resources of the counties of Antrim, Grand Traverse, Benzie, and Leelanaw in the Lower Peninsula of Michigan." Ann Arbor, 1866.

Black, with dotted lines and geological indications.

380.

**1867—Newberry** (J. S.). Geological map of Ohio.

Accompanying "Stebbins's atlas of Ohio." (———.)

Unseen.

381.

9—**Brooks** (T. B.). Map of Republic Mountain and vicinity, Marquette County, Michigan. Scale, $\frac{1}{4800}$ = 400 feet to the inch.

Accompanying "Geological survey of Michigan." Atlas folio. 1873. Plate VI. New York, 1873.

382.

9—**Credner** (H.). Geognostische Uebersichts-Karte der Eisenregionen der oberen Halbinsel von Michigan.

Accompanying "Die vorsilurischen Gebilde der oberen Halbinsel von Michigan in Nord-America." Zeitsch. Deut. Geol. Gesells. Vol. XXI. Taf. VIII. Berlin, 1869.

Black etching, and geological indications.

383.

9—**Whittlesey** (Charles). Geological map of Eastern Ohio.

Accompanying "The physical geology of Eastern Ohio." Memoirs Boston Soc. Nat. Hist., Vol. I, p. 598. Boston, 1869.

384.

70—**Newberry** (J. S.). Preliminary geological map of Ohio.

Accompanying "Geological survey of Ohio", 1869. Columbus, 1871.

385.

71—**Gilbert** (G. K.) Map of Lucas County, colored to show the geological structure.

Accompanying "Geological survey of Ohio", Geology. Vol. I, p. 573. Columbus, 1873.

386.

73—**Brooks** (T. B.). Map of the Menominee iron region, upper peninsula, Michigan. Scale, 7,040 feet to one inch or $\frac{3}{4}$ inch to a mile.

Accompanying "Geological survey of Michigan." Atlas folio. 1873. Plate IV. New York, 1873.

387.

873—**Brooks** (T. B.). Map of the Marquette iron region, upper peninsula, Michigan. Scale, 7,040 feet to the inch.

Accompanying "Geological survey of Michigan." Atlas folio. 1873. Plate III. New York, 1873.

388.

873—**Stevenson** (J. J.). Map to show limits of the upper coal measures in Ohio.

Accompanying "The upper coal measures west of the Alleghany Mountains." Annals of Lyceum of Natural History of New York, Vol. X. Plate XII. New York, 1874.

389.

**1873—Borden** (W. W.). Geological maps of Clark and Floyd Counties Indiana.

Accompanying "Fifth annual report of the geological surv. of Indiana made during the year 1873", by E. T. Cox. Indianapolis, 1874.

390.

**1873—Collett** (John). (Geological) map of Lawrence County, Indiana

Accompanying "Fifth annual report of the geological surv. of Indiana Indianapolis, 1874.

Black, with geological indications.

391.

**1873—Newberry** (J. S.). Geological map of Ohio.

Accompanying "Paleontology and the moral sense," by Charles Whittlesey p. 9. Cleveland, 1873.

See **Newberry** (J. S.), 1867—No. 384.

392.

**1873—Newberry** (J. S.). Geological map of Cuyahoga County.

Accompanying "Geological survey of Ohio." Geology. Vol. I, p. 171. Columbus, 1873.

393.

**1873—Newberry** (J. S.). Geological map of Clarke County.

Accompanying "Geological survey of Ohio." Geology. Vol. I, p. 480. Columbus, 1873.

394.

**1873—Newberry** (J. S.). Geological map of Summit County.

Accompanying "Geological survey of Ohio." Geology. Vol. I, p. 201. Columbus, 1873.

395.

**1873—Orton** (Edward). Map showing lines of junction of Cincinnati group and Clinton limestone, or of Lower and Upper Silurian, Southwestern Ohio. Scale, 5 miles to 1 inch.

Accompanying "Geological survey of Ohio." Geology. Vol. I, p. 413. Columbus, 1873.

396.

**1873—Pumpelly** (Raphael). Map to accompany the cross-sections the Portage Lake district. Scale, 1=12,000.

Accompanying "Geological survey of Michigan." Atlas folio. 1873. Pls XIV*a* and XIV*b*. New York, 1873.

A. R. Marvine and L. G. Emerson, assistants; in two sheets.

397.

**1873—Pumpelly** (Raphael). Map to accompany the cross sections of Eagle River district. Scale, 1 : 4,800 (or) 400 feet to an inch.

Accompanying "Geological survey of Michigan." Atlas folio. 1873. Pl XX. New York, 1873.

A. R. Marvine and S. B. Ladd, assistants.

405.

73—**Read** (M. C.). Geological map of Ashtabula, Lake, Geauga, and Trumbull Counties.

Accompanying "Geological survey of Ohio." Geology. Vol. I, p. 483. Columbus, 1873.

399.

3—**Rominger** (Charles), **Pumpelly** (Raphael) & **Brooks** (T. B.). Map of the Upper Peninsula. Palæzoic rocks, by C. Rominger; copper-bearing rocks, by R. Pumpelly; iron-bearing rocks (Huronian), by T. B. Brooks; Laurentian rocks, by Brooks & Pumpelly. Scale, 13 miles to an inch, $\frac{1}{633680}$.

Accompanying "Geological survey of Michigan." Atlas folio. 1873. Plate I. New York.

400.

—**Whittlesey** (Charles). Geological map of Ohio. Geological outlines, by Charles Whittlesey, 1856.

Accompanying "Paleontology and the moral sense," p. 8. Cleveland, 1873.

See **Whittlesey** (Charles), 1856, a reduction in black, with indications by numbers—No. 376.

401.

—**Winchell** (N. H.). Geological map of Wyandot County.

Accompanying "Geological survey of Ohio." Geology. Vol. I, p. 625. Columbus, 1873.

402.

—**Winchell** (N. H.). Geological map of Marion County.

Accompanying "Geological survey of Ohio." Geology. Vol. I, p. 640. Columbus, 1873.

403.

3—**Winchell** (N. H.). Geological map of Seneca County.

Accompanying "Geological survey of Ohio." Geology. Vol. I, p. 611. Columbus, 1873.

404.

3—**Winchell** (N. H.). Geological map of Sandusky County.

Accompanying "Geological survey of Ohio." Geology. Vol. I, p. 593. Columbus, 1873.

405.

4—**Newberry** (J. S.). Geological map of Erie County, and the Islands.

Accompanying "Geological survey of Ohio." Vol. II, p. 185. Columbus, 1874.

406.

74—**Orton** (Edward). Geological map of Highland, Ross, and Pike Counties.

Accompanying "Geological survey of Ohio," Vol. II, p. 611. Columbus, 1874.

407.

**1874—Orton** (Edward). Geological map of Green County.
Accompanying "Geological survey of Ohio," Vol. II, p. 659. Columbus, 1874.

408.

**1874—Winchell** (N. H.). Geological map of Defiance County.
Accompanying "Geological survey of Ohio," Vol. II, p. 422. Columbus, 1874.

409.

**1874—Winchell** (N. H.). Geological map of Ottawa County.
Accompanying "Geological survey of Ohio," Vol. II, p. 227. Columbus, 18

410.

**1874—Winchell** (N. H.). Geological map of Crawford County.
Accompanying "Geological survey of Ohio," Vol. II, p. 237. Columbus, 18

411.

**1874—Winchell** (N. H.). Geological map of Morrow County.
Accompanying "Geological survey of Ohio," Vol. II, p. 253. Columbus, 18

412.

**1874—Winchell** (N. H.). Geological map of Delaware County.
Accompanying "Geological survey of Ohio," Vol. II, p. 272. Columbus, 18

413.

**1874—Winchell** (N. H.). Geological map of Van Wert County.
Accompanying "Geological survey of Ohio," Vol. II, p. 314. Columbus, 18

414.

**1874—Winchell** (N. H.). Geological map of Union County.
Accompanying "Geological survey of Ohio," Vol. II, p. 324. Columb
1874.

415.

**1874—Winchell** (N. H.). Geological map of Paulding County.
Accompanying "Geological survey of Ohio," Vol. II, p. 336. Columb
1874.

416.

**1874—Winchell** (N. H.). Geological map of Harding County.
Accompanying "Geological survey of Ohio," Vol. II, p. 354. Columbu
1874.

417.

**1874—Winchell** (N. H.). Geological map of Hancock County.
Accompanying "Geological survey of Ohio," Vol. II, p. 358. Columbu
1874.

418.

74—**Winchell** (N. H.). Geological map of Wood County.
Accompanying "Geological survey of Ohio," Vol. II, p. 368. Columbus, 1874.

419.

4—**Winchell** (N. H.). Geological map of Putnam County.
Accompanying "Geological survey of Ohio," Vol. II, p. 387. Columbus, 1874.

420.

1—**Winchell** (N. H.). Geological map of Henry County.
Accompanying "Geological survey of Ohio," Vol. II, p. 416. Columbus, 1874.

421.

1—**Sauvage** (M. E.). Carte de la région ferrifère de Michigan. Scale, $\frac{1}{1008440}$.
Accompanying "Notice sur les minérais de Fer du Lac Supérieur." Annales des mines, 7e série, tome VIII, Pl. I. Paris, 1875.
In black etching and one color.

422.

5—**Whittlesey** (Charles). Physical geology of Lake Superior. Scale, 50 miles to $\frac{7}{8}$ inch.
Accompanying "Physical geology of Lake Superior." Proceedings of American Association for the Advancement of Science, Vol. XXIV, p. 64. Salem, 1876.

423.

3—**Rominger** (Charles). Geological map of the lower peninsula. Scale, 13 miles to one inch, or 1:823,680.
Accompanying "Geological survey of Michigan," Vol. III, Part I. New York, 1876.

424.

3—**Spencer** (J. W.). Keweenaw Point. Scale, 20 miles to the inch.
Accompanying "On the Nipigon or copper-bearing rocks of Lake Superior," with notes on copper mining in that region. The Canadian Naturalist and Geologist, new series, Vol. VIII, p. 55. Montreal, 1878.
Black etching.

425.

8—**Hill** (F. C.) Map of Logan and Champaign Counties.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 491. Columbus, 1878.

426.

8—**Newberry** (J. S.). Map of Portage County.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 133. Columbus, 1878.

427.

**1878—Orton** (Edward). Map of Butler County.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 399. Columbus, 1878.

428.

**1878—Orton** (Edward). Map of Preble County.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 404. Columbus, 1878.

429.

**1878—Orton** (Edward). Map of Franklin County.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 600. Columbus, 1878.

430.

**1878—Orton** (Edward). Map of Warren County.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 3[illegible]8. Columbus, 1878.

431.

**1878—Read** (M. C.). Map of Huron County.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 2[illegible]9. Columbus, 1878.

432.

**1878—Read** (M. C.). Map of Richland, Ashland, Wayne, Knox, Holm[illegible]s, Coshocton, and Licking Counties.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 5[illegible]9. Columbus, 1878.

433.

**1878—Stevenson** (J. J.). Map to show limits of the Upper Coal Measures in Ohio, north from Central Ohio R. R.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 209. Columbus, 1878.
In black, with a dotted line showing the western and northern boundary of the Pittsburgh coal.

434.

**1878—Weat** (A. W.). Map of Medina County.
Accompanying "Geological survey of Ohio." Geology. Vol. III, p. 363. Columbus, 1878.

435.

**1879—Newberry** (J. S.), **Andrews** (E. B.), **Orton** (Edward), **Read** (M. C.), **Gilbert** (G. K.), **Winchell** (N. H.), and **Hill** (F. C.). Geological map of the State of Ohio.
Accompanying "Geological survey of Ohio." Atlas folio. New York, 1879.
Six sheets, forming a geological atlas of the State of Ohio. Published by authority of the legislature.

436.

**ıt (C. E.). Map of the Menominee iron district and adjacent ›ry.**

›mpanying "Annual report of the commissioner of mineral statistics of ıte of Michigan for 1880." Lansing, 1881.

437.

**(John). Outline geological map of Indiana.**

mpanying "Second annual report of the department of statistics and y of Indiana," p. 450. Indianapolis, 1880.
k etching and geological indications. It is reprinted in the eleventh report of the State geologist, p. 12, 1881.
Collet (John) 1881—No. 441.

438.

**(John). Map of Putnam County, Indiana.**

›mpanying "The geology of Putnam County." Second annual report department of statistics and geology of Indiana, p. 397. Indianapolis,

k etching and geological indications.

439.

**e (G. K.). Map of Munroe County.**

›mpanying "Geology of Munroe County." Second annual report of the ment of statistics and geology of Indiana, p. 427. Indianapolis, 1880.
k, with geological indications.

440.

**(Edward). Map of Eastern Ohio.**

mpanying "Review of stratigraphical geology of Eastern Ohio," in report of the Secretary of State, 1879. Columbus, 1880.
k, with geological indications.

441.

**(John). Outline geological map of Indiana.**

›mpanying "Eleventh annual report of the State geologist of Indiana," Indianapolis, 1881.
Collet (J.), 1880—No. 437.

442.

**(John). Map of Shelby County.**

›mpanying "Geology of Shelby County accompanying eleventh annual of State geologist of Indiana," p. 55. Indianapolis, 1882.
k etching and geological indications.

443.

**ı (R. T.). Map of Fountain County, Indiana.**

›mpanying "Fountain County geology, geography, &c.; eleventh an›port of the State geologist of Indiana," p. 89. Indianapolis, 1882.
k etching and geological indications.

444.

**1881—Phinney** (A. J.). Map of Delaware County.

Accompanying "Geology of Delaware county; eleventh annual report of the State geologist of Indiana," p. 126. Indianapolis, 1882.

Black etching and geological indications.

445.

**1881—Elrod** (M. N.). Map of Bartholomew County, Indiana.

Accompanying "Geology of Bartholomew County; eleventh annual report of the State geologist of Indiana," p. 150. Indianapolis, 1882.

Black etching and geological indications.

446.

**1881—Rominger** (Charles). Geological map of the environs of Marquette, Negaunee, and Ishpeming. Scale, 1½ inch for 1 mile.

Accompanying "Geol. surv. of Michigan, upper peninsula, 1878-18[illegible] Vol. IV. New York, 1881.

447.

**1881—Winchell** (N. H.). Sketch map of Isle Royale, Lake Superior.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota," tenth annual report, Plate III. St. Paul, 1882.

Black, with geological indications.

448.

—**Owen** (D. D.). Chart of the great Illinois coal field.

Accompanying "Report of a geological exploration of part of Iowa, Wisconsin, and Illinois, made in the autumn of the year 1839." (Washington), 1844.

449.

—**Owen** (D. D.). Geological section from the mouth of Rock River through the blue mounds to the Wisconsin River in connection with a geological chart of part of Iowa, Wisconsin, and Illinois.

Accompanying "Report of geological exploration of parts of Iowa, Wisconsin, and Illinois, made in the autumn of the year 1839." Plate III. (Washington), 1844.

450.

—**Owen** (D. D.). Geological chart of part of Iowa, Wisconsin, and Illinois.

Accompanying "Report of a geological exploration of part of Iowa, Wisconsin, and Illinois, made in the autumn of the year 1839." (Washington), 1844.

An edition of the report was made in 1840, but without the accompanying charts. Washington is not named in the title page as the place of publication; the only inscription is, "Ordered to be printed by the Senate of the United States."

451.

—**Owen** (D. D.). Provisional geological map of part of the Chippewa land district of Wisconsin, with part of Iowa, and of Minnesota Territory, to illustrate the report of a geological reconnaissance made in 1847.

Accompanying "Report of a geological reconnaissance of the Chippewa land district of Wisconsin; and incidentally of a portion of the Kickapoo country, and of a part of Iowa and of the Minnesota Territory." (Washington. 1849).

Neither date nor place of publication is given, but very likely Washington is the place.

452.

—**Norwood** (J. G.). Geological map of parts of Minnesota and Wisconsin, designed to show portions of the rock formations now concealed by drift.

Accompanying "Report of a geological survey of Wisconsin, Iowa, and Minnesota, and incidentally of a portion of Nebraska Territory," by D. D. Owen. 4°. Volume of illustrations. Philadelphia, 1852.

453.

**1852—Owen** (Richard). Geological map, coast view and section of Pigeon Point, northwest coast of Lake Superior.

Accompanying "Report of a geological survey of Wisconsin, Iowa, and Minnesota, and incidentally of a portion of Nebraska Territory," by D. D. Owen. 4°. Volume of illustrations. Philadelphia, 1852.

454.

**1855—Lapham** (I. A.). A geological map of Wisconsin. New York, 1855.

One sheet folio.

455.

**1857—[Hall** (James), **Whitney** (J. D.), and **Worthen** (A. H.)]. Geological map of the eastern half of the State of Iowa; by legislative authority.

Accompanying "Report of the geological survey of the State of Iowa" Vol. I, Part I, p. 146. (Albany, N. Y.), 1858.

456.

**1857—Norwood** (J. G.). Illinois geological survey. Diagram of the State of Illinois (colored geologically). Drawn by H. A. Uffers.

Accompanying "Abstract of a report on Illinois coals, and a general notice of coal fields." Chicago, 1857.

457.

**1859—Whittlesey** (Charles). Geological map of the country on the upper waters of the Menominee, Peshattego, and Oconto Rivers. Scale, $\frac{4}{10}$ of an inch to the mile.

Accompanying "Paleontology and the moral sense," by C. Whittlesey. Cleveland, 1873.

458.

**1860—Whittlesey** (Charles). Geological map of the Penokie Range, Ashland County, Wisconsin. Scale, 6 miles to 1 inch.

Accompanying "Wisconsin geological survey." Vol. III, Appendix A, p. 215. Madison, 1880.

Reissued in black etching, one small sheet octavo, in "Paleontology and the moral sense." Cleveland, 1873.

See **Whittlesey** (Charles), 1873—No. 476.

459.

**1862—Whitney** (J. D.). Geological map of the lead region in the States of Wisconsin, Illinois, and Iowa.

Accompanying "Report of geological survey of the Upper Mississippi lead region." Extract from "Report of the geological survey of the State of Wisconsin." Vol. I. Albany, 1862.

460.

4—**Engelmann** (Henry). Map of Harding County.

Accompanying "Geological survey of Illinois." Vol. I, p. 350. Springfield, 1866.

461.

8—[**Whitney** (J. D.)]. Geological map of the northwest corner of Illinois.

Accompanying "Geological survey of Illinois." Vol. I, p. 154. Springfield, 1866. Called in the list of illustrations "Geological map of the Galena lead region." On the map there is no name of author, no date, and no scale.

462.

6—**Whittlesey** (Charles). Mouth of Baptism River.

Accompanying "A report of explorations in the mineral regions of Minnesota during the years 1848, 1859, and 1864," p. 26. Cleveland, 1866.

Black etching and letters corresponding to geological indications in the text.

463.

66—**Whittlesey** (Charles). Portion of the north shore in towns 51 and 52 north, ranges 12 and 13 west, St. Louis County, Minnesota. Scale, ½ inch to the mile.

Accompanying "A report of explorations in the mineral regions of Minnesota during the years 1848, 1859, and 1864," p. 35. Cleveland, 1866.

Black etching and letters corresponding to geological indications in the text.

464.

8—**Whittlesey** (Charles). Mouth of the Ke-shik-on-se-kan or Cedar River, and Beaver Bay.

Accompanying "A report of explorations in the mineral regions of Minnesota during the years 1848, 1859, and 1864," p. 29. Cleveland, 1866.

Black etching and letters corresponding to geological indications in the text.

465.

—**Freeman** (H. C.). Map of La Salle County.

Accompanying "Geological survey of Illinois," Vol. III, p. 257. Springfield, 1868.

466.

—**Lapham** (I. A.). A new geological map of Wisconsin, prepared mostly from original observations. Scale, 15 miles to 1 inch. Milwaukee, 1869.

Folio.

467.

0—**White** (C. A.). Geological map model of Iowa.

Accompanying "Report on the geological survey of the State of Iowa," Vol. I, p. 32. Des Moines, 1870.

468.

**1870—White** (C. A.). Geological map of the State of Iowa.

Accompanying "Report on the geological survey of the State of Iowa," Vol. II. Des Moines, 1870.

469.

**1871—Kloos** (J. H.). Orientirungs-Karte zu den geologischen Notizen aus Minnesota.

Accompanying "Geologische Notizen aus Minnesota." Zeitsch. Deut. Geol. Gesells., Vol. XXIII, Taf. VIII, p. 472. Berlin, 1871.

Black etching. An English translation and reprint of the map has appeared in the Tenth annual report of the geological survey of Minnesota, for the year 1881.

470.

**1871—White** (C. A.). Sketch map of the State of Iowa.

Accompanying "American geological surveys." The Geological Magazine, 1st series, Vol. VIII, p. 222. London, 1871.

Black etching.

471.

**1872—Winchell** (N. H.). Preliminary geological map of Minnesota.

Accompanying "The annual report of the board of regents of the University of Minnesota for 1872." Saint Paul, 1873.

472.

**1872—Winchell** (N. H.). Preliminary geological map of Minnesota.

Accompanying "The first annual report for the year 1872 of the geological and Natural History Survey of Minnesota, p. 45. Saint Paul, 1873.

473.

**1873—Irving** (R. D.). Outline geological map of northern Wisconsin. Scale, 15 miles to the inch.

Accompanying "On the age of the copper-bearing rocks of Lake Superior, &c. Amer. Journ. Silliman, 3d series, Vol. VIII, Plate IV, p. 83. New Haven, 1874.

Black etching and geological indications.

474.

**1873—Irving** (R. D.). Map showing the formations at the junction of Bad River and Tyler's Fork.

Accompanying "Wisconsin geological survey." Vol. III, Part III, Plate XVI, p. 185. Madison, 1880.

Black etching, with geological indications.

475.

**1873—Irving** (R. D.). Map showing the formations along Black River, Jackson County.

Accompanying "Wisconsin geological survey." Vol. II, Part III, Plate XVII, p. 493. Madison, 1877.

Black etching.

476.

3—**Whittlesey** (Charles). Geological map of the Penokie Range, Ashland County, Wisconsin. Scale, 6 miles to 1 inch.

Accompanying "Paleontology and the moral sense." Cleveland, 1873.
See **Whittlesey** (Charles) 1860—No. 458.

477.

74—**Irving** (R. D.). Wood and portions of Clark, Jackson, Marathon, and Portage Counties. Scale, 3 miles to the inch.

Accompanying "Wisconsin geological survey." Atlas, Vol. II, Folio, Plate No. XV. Milwaukee, 1877.

478.

74—**Winchell** (N. H.). Geological map of the county of Freeborn, Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Third Annual Report, p. 148. Saint Paul, 1875.

479.

74—**Winchell** (N. H.). Geological map of Mower County, Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Third Annual Report, p. 166. Saint Paul, 1875.

480.

75—**Harrington** (M. W.). Geological map of Olmsted County, Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Fourth Annual Report, p. 75. Saint Paul, 1876.

481.

75—**Harrington** (M. W.). Geological map of Dodge County, Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Fourth Annual Report, p. 97. Saint Paul, 1876.

482.

75—**Harrington** (M. W.). Geological map of Steele County, Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Fourth Annual Report, p. 107. Saint Paul, 1876.

483.

75—**Winchell** (N. H.). Geological map of Fillmore County, Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Fourth Annual Report, p. 13. Saint Paul, 1876.

484.

1875—**Worthen** (A. H.). Geological map of the State of Illinois ton, 1875.

In two large sheets, lithographed at Boston, published by Legislative ity; there is no scale nor place of publication on it; it was drawn ington, W., St. John, O. H., and Worthen, C. K.

485.

1876—**Chamberlin** (T. C.). Map of quaternary formations of Wisconsin. Scale, 1 inch=12 miles.

Accompanying "Wisconsin geological survey." Atlas, Vol. II Plate II. Milwaukee, 1877.

486.

1876—**Chamberlin** (T. C.). Door and parts of Kewaunee, Brow gamie, Shawano, and Oconto Counties. Scale, 3 miles to t

Accompanying "Wisconsin geological survey." Atlas, Vol. II. Fo XII. Milwaukee, 1877.

487.

1876—**Chamberlin** (T. C.). Kenosha, Racine, Milwaukee, Wa Walworth, Jefferson, and parts of Rock, Dodge, Was and Ozaukee Counties. Scale, 3 miles to the inch.

Accompanying "Wisconsin geological survey." Atlas, Vol. I Plate X. Milwaukee, 1877.

488.

1876—**Chamberlin** (T. C.). Fond du Lac, Sheboygan, Manitowoc, ( Winnebago, and parts of Dodge, Washington, Ozaukee, nee, Brown, Outagamie, and Waupaca Counties. Scale to the inch.

Accompanying "Wisconsin geological survey." Atlas, Vol. I Plate XI. Milwaukee, 1877.

489.

1876—**Chamberlin** (T. C.). Map of subsoils of Eastern Wisconsin 1 inch = 12 miles.

Accompanying "Wisconsin geological survey." Atlas of Vol. I Plate III. Milwaukee, 1877.

490.

1876—**Chamberlin** (T. C.), **Irving** (R. D.), **Strong** (M.). Iowa, La Green, range VI in Dane, and range III in Sauk, by M. Dane and ranges IV, V, VI, in Sauk, by R. D. Irving. I T. C. Chamberlin. Scale 3 miles to the inch.

Accompanying "Wisconsin geological survey." Atlas, Vol II. Fol XIII. Milwaukee, 1877.

491.

76—**Chamberlin** (T. C.), and **Irving** (R. D.). Juneau, Adams, Waushara, Marquette, Sauk, Columbia, and Green Lake, north of Fox River, by R. D. Irving. Green Lake and Dodge by T. C. Chamberlin. Scale, 3 miles to the inch.

Accompanying "Wisconsin geological survey." Atlas, Vol. II, folio. Plate XIV. Milwaukee, 1877.

492.

76—**Irving** (R. D.). Details of the structure of the Huronian series in the vicinity of Penokee Gap, T. 44, R. 3 W. Ashland County. Scale, $\frac{1}{1320}$.

Accompanying "Wisconsin geological survey." Atlas, Vol. III, folio. Plate XXIII. Milwaukee, 1879.

493.

76—**Irving** (R. D.), and **Strong** (M.). Trempealeau, La Crosse, Monroe, Vernon, Sauk, Richland, and Crawford Counties, by M. Strong. Juneau and Jackson Counties, by R. D. Irving. Scale, 3 miles to 1 inch.

Accompanying "Wisconsin geological survey." Atlas, Vol. III, folio. Plate XVII. Milwaukee, 1879.

494.

3—**Irving** (R. D.). Geological map of the Four Lake country of Dane County.

Accompanying "Wisconsin geological survey." Vol. II. Part III. Plate XXVI A, p. 613. Madison, 1877.

Black etching.

495.

3—**Irving** (R. D.). Map of Devil's Lake gorge.

Accompanying "Wisconsin geological survey." Vol. II. Part III. Plate XIX, p. 507. Madison, 1877.

Black etching.

496.

3—**Irving** (R. D.). Map showing the succession of layers along the gorge of the Montreal River. T. 47, R. J. E. Scale, 10 inches to the mile.

Accompanying "Wisconsin geological survey." Vol. III. Part III. Plate XIX, p. 192. Madison, 1880.

Black etching, with geological indications and numbers corresponding to text.

497.

6—**Irving** (R. D.). Map showing the succession of layers along the Montreal River. T. 47, R. J. E. Scale, 2¼ inches = 1 mile.

Accompanying "Wisconsin geological survey." Vol. III. Part III. Plate XVIII, p. 190. Madison, 1880.

Black etching, with geological indications.

498.

1876—**Strong** (M.). Grant and parts of Lafayette, Iowa, Richla Crawford Counties.

Accompanying "Wisconsin geological survey." Atlas, Vol. I Plate XVI. Milwaukee, 1877.

499.

1876—**Strong** (M.). Geology and topography of the lead region.

Accompanying "Wisconsin geological survey." Atlas, Vol. I Plates III, IV, V, VI, VII. Milwaukee, 1877.

In five sheets.

500.

1876—**Strong** (M.), and **Wooster** (L. C.). Polk and Barron Counti parts of Dunn, Saint Croix, Chippewa, and Burnett Cc towns 32–38, inclusive, by M. Strong. Town 31, by Wooster.

Accompanying "Wisconsin geological survey." Atlas, Vol. II Plate XIX. Milwaukee, 1879.

501.

1876—**Winchell** (N. H.). Geological map of Houston County, Min

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." I nual Report, p. 9. Saint Paul, 1877.

502.

1876—**Winchell** (N. H.). Geological map of Hennepin County, sota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." I nual Report, p. 131. Saint Paul, 1877.

503.

1876—**Winchell** (N. H.). Map of the vicinity of the Fall of Saint A intended to illustrate the surface geology (Minnesota). I inch to 1 mile.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." I nual Report, p. 156. Saint Paul, 1877.

504.

1873–1877—**Irving** (R. D.). Map of part of T. 44, R. 3 W., desi show the relations of the Laurentian, Huronian, and Ke systems.

Accompanying "Wisconsin geological survey." Vol. III, Part II XV, p. 145. Madison, 1880.

505.

1877—**Irving** (R. D.). Map showing the relative positions of the i Archæan areas of Wisconsin. Scale, 1 inch to 24 miles.

Accompanying "Wisconsin geological survey." Vol. II, Part III XVIII, p. 501. Madison, 1877.

Black etching.

506.

77—**Irving** (R. D.). Map of part of Wisconsin, designed to show the main facts with regard to the distribution of the glacial drift and other quaternary deposits.

Accompanying "Wisconsin geological survey." Vol. II, Part III. Plate XXV A, p. 608. Madison, 1877.

507.

77—**Irving** (R. D.). Outline of an area of Trenton limestone, near Columbus. Scale, 4 miles to the inch.

Accompanying "Wisconsin geological survey." Vol. II, Part III. p. 614. Madison, 1877.

Black etching.

508.

77—**Irving** (R. D.). Details of the structure of the Huronian or iron-bearing series of Ashland and Lincoln Counties. Scale, 3.6 inches = 1 mile.

Accompanying "Wisconsin geological survey." Atlas, Vol. III, folio. Plates XXIV, XXV, XXVI. Milwaukee, 1879.

In three sheets.

509.

7—**Sperry** (L. B.). Geological map of Rice County, Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Sixth Annual Report, p. 114. Minneapolis, 1878.

510.

7—**Sweet** (E. T.). Outline geological map of a portion of Northern Wisconsin.

Accompanying "Wisconsin geological survey." Vol. III, Part V. Plate XXXIV, p. 330. Madison, 1880.

Black etching.

511.

7—**Sweet** (E. T.). Outline structural map of the Lower Black River Falls. Scale 400 feet to the inch.

Accompanying "Wisconsin geological survey." Vol. III, Part V, p. 343. Madison, 1880.

Black etching and numbers corresponding to geological indications in the text.

512.

7—**Winchell** (N. H.). Geological map of Ramsey County, Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Sixth Annual Report, p. 66. Minneapolis, 1878.

513.

**1877—Winchell** (N. H.). Geological map of Rock and Pipestone ties, Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." nual Report, p. 92. Minneapolis, 1878.

Black, with geological inscriptions.

514.

**1877—Wright** (C. E.). Penokie iron range west of Gap.

Accompanying "Wisconsin geological survey." Atlas, Vol. Plate XXVII. Milwaukee, 1879.

515.

**1878—Irving** (R. D.). Map showing the succession of layers a Potato River. Scale, 6 inches = 1 mile.

Accompanying "Wisconsin geological survey." Vol. III, Part XVII, p. 188. Madison, 1880.

Black etching, with geological indications.

516.

**1878—Irving** (R. D.). Geological map and sections illustrat structure of the regions drained by the Bad and Rivers. Scale, 2 miles to the inch.

Accompanying "Wisconsin geological survey." Atlas, Vol. Plate XXII. Milwaukee, 1879.

517.

**1878—Warren** (G. K.). (No title.)

Accompanying "Valley of the Minnesota River and of the River, to the junction of the Ohio; its origin considered." Ame Silliman. 3rd series, Vol. XVI, Diagram E. New Haven, 1878.

Black etching, with geological indications in the text.

518.

**1879—Brooks** (T. B.). Sturgeon River.

Accompanying "Wisconsin geological survey." Vol. III, Part V I, p. 452. Madison, 1880.

Black etching, and geological indications.

519.

**1879—Brooks** (T. B.). Big Quinnesec Falls. Scale, $\frac{1}{4}$ mile to 1

Accompanying "Wisconsin geological survey." Vol. III, Part V III, p. 472. Madison, 1880.

Black etching and geological indications.

520.

**1879—Brooks** (T. B.). Little Quinnesec Falls and Sand Portage Scale, $\frac{1}{4}$ of a mile to the inch.

Accompanying "Wisconsin geological survey." Vol. III, Part V II, p. 468. Madison, 1880.

Black etching and geological indications.

521.

9—**Brooks** (T. B.). Twin and Four Ft. Falls, Menominee River. Scale, $\frac{1}{4}$ of a mile to the inch.

Accompanying "Wisconsin geological survey." Vol. III, Part VII. Plate IV, p. 475. Madison, 1880.

Black etching and geological indications.

522.

9—**Brooks** (T. B.). Pine and Poplar Rivers. Scale, $\frac{1}{2}$ mile to the inch.

Accompanying "Wisconsin geological survey." Vol. III, Part VII. Plate V, p. 477. Madison, 1880.

Black etching and geological indications.

523.

9—**Brooks** (T. B.). Commonwealth and Eagle iron belts. Scale, $\frac{1}{2}$ mile to the inch.

Accompanying "Wisconsin geological survey." Vol. III, Part VII. Plate VI, p. 481. Madison, 1880.

Black etching and geological indications.

524.

9—**Brooks** (T. B.). Hypothetical sketch of the rock structure near Lake Eliza.

Accompanying "Wisconsin geological survey." Vol. III, Part VII. Plate VIII, p. 484. Madison, 1880.

Black etching and geological indications.

525.

9—**Brooks.** (T. B.). Lower Brulé, Michigamme, and Paint Rivers. Scale, $\frac{1}{2}$ mile to the inch.

Accompanying "Wisconsin geological survey." Vol. III, Part VII. Plate IX, p. 492. Madison, 1880.

Black etching and geological indications.

526.

79—**Brooks** (T. B.). Geological sketch of the Menominee iron region, showing approximatively the distribution and folds, illustrating report, Vol. III, Part VII. Scale, 3 miles to the inch.

Accompanying "Wisconsin geological survey." Atlas, Vol. III, folio. Plate XXIX. Milwaukee, 1879.

527.

79—**Brooks** (T. B.). and **Wright** (C. E.) Map of the Menominee iron region, including Pine River district, Oconto County, and in part the Sturgeon River district, Michigan. Scale, $\frac{3}{4}$ inch to 1 mile.

Accompanying "Wisconsin geological survey." Atlas, Vol. III, folio. Plate XXVIII. Milwaukee, 1879.

528.

**1879—Irving** (R. D.). Map of Wisconsin and adjoining portions of
igan, Illinois, Iowa, and Minnesota, showing geological str
positions of the principal mineral districts, &c. Scale 2
to 1 inch.

Accompanying "The mineral resources of Wisconsin." Trans. Am
Mining Engrs., Vol. VIII, p. 506. Easton, Pa., 1880.

A well executed and very clear geological map.

529.

**1879—Strong** (M.). Map of Northwestern Wisconsin, designed t
the main features of the surface geology.

Accompanying "Wisconsin geological survey." Vol. III, Part V
XXXVII, p. 383. Madison, 1880.

530.

**1879—Strong** (M.) and **Sweet** (E. T.). Douglas County, and parts
field, Burnett, and Ashland Counties; north of township
E. T. Sweet, south of township 44, by M. Strong.

Accompanying, "Wisconsin geological survey." Atlas, Vol. I
Plate XX. Milwaukee, 1879.

531.

**1879—Strong** (M.) **Sweet** (E. T.) and **Irving** (R. D.). Parts of A
Bayfield, and Lincoln Counties. Ashland County, the
island, Lincoln County, and townships 44–51, ranges 4 and
Bayfield County, by R. D. Irving; townships 43–46, range
7 west, by M. Strong; township 47–51, ranges 6 and 7 w
E. T. Sweet. Scale, 3 miles to the inch.

Accompanying "Wisconsin geological survey." Atlas, Vol. I
Plate XXI. Milwaukee, 1879.

532.

**1879—Wooster** (L. C.) and **Strong** (M.). Saint Croix, Chippewa, a
Claire Counties, T. XXV, Pepin County, and T. 27, range
18 W., T. 26, range 15 and 16 W., and parts of T. 25, r
W., and T. 26, range 17 W., Pierce County, by L. C. W
Trempealeau, Buffalo, and the remainder of Pierce and P
M. Strong. Scale, 3 miles to the inch.

Accompanying "Wisconsin geological survey." Atlas, Vol. I
Plate XVIII. Milwaukee, 1879.

533.

**1879—Wright** (C. E.) Map of the Menominee iron district and a
territory.

Accompanying "Wisconsin geological survey." Atlas, Vol. I
Plate XXX. Milwaukee, 1879.

534.

80—**Irving** (R. D.). Quaternary map of the eastern Lake Superior district.

Accompanying "Wisconsin geological survey." Vol. III, Part III. Plate XX, p. 211. Madison, 1880.

535.

80—**Irving** (R. D.). Outline geological map of northern Wisconsin. Scale, 15 miles to the inch.

Accompanying "Wisconsin geological survey." Vol. III, Part I. Plate IX, p. 3. Madison, 1880.

536.

0—**Wright** (E. C.). No title. Section 16, township 44 N., range 5 W., Wisconsin.

Accompanying "Wisconsin geological survey." Vol. III, Part IV. Plate XXVII, p. 286. Madison, 1880.

Colored and with geological indications.

537.

1—**Kloos** (J. H.). Orientirungs-Karte zu den geologischen Notizen aus Minnesota.

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Tenth Annual Report. Saint Paul, 1881.

See **Kloos** (J. H.), 1871—No. 469.

538.

1—**Winchell** (N. H.) Sketch map of the canoe trail from Ogishke Muncie Lake to the mouth of Poplar River (Lake Superior).

Accompanying "Geological and Nat. Hist. Surv. of Minnesota." Tenth Annual Report, Plate I. St. Paul, 1882.

Black with geological indications.

539.

81—**Winchell** (N. H.). Sketch map of the iron trail for canoes from Grand Marais to Iron Lake (Lake Superior).

Accompanying "Geological and Natural Hist. Surv. of Minnesota." Tenth Annual Report, Plate II. Saint Paul, 1882.

Black with geological indications.

B.—Nelson Sayler, in 1865, advertised the publication of a "Geological map of Illinois," but it was never published.

## XII.—SOUTHERN STATES, COMPRISING VIRGINIA, WEST VIR KENTUCKY, TENNESSEE, MISSISSIPPI, ALABAMA, FL( GEORGIA, SOUTH CAROLINA, AND NORTH CAROLINA.

540.

**1827—Mitchell** (Dr.). A geological map of the eastern half of Carolina.

Never published, and has disappeared. Not seen.

541.

**1833—Peck** (J.). Geological map of the mining districts in the Georgia, western parts of North Carolina, and in East Ten Scale, 10 miles to § of an inch.

Accompanying "Geological and mineralogical account of the mi tricts in the State of Georgia," etc. Amer. Jour. Silliman, Vol. XXI Haven, 1833.

This map has merely geological indications on it.

542.

**1839—Troost** (Gerard). Geological map of the State of Tennes

Accompanying "Fifth geological report to the general assembly o see," p. 8 Nashville, 1840.

543.

**1839—Troost** (Gerard). Geological map of Cocke County, Ea nessee.

Accompanying "Fifth geological report to the general assembly o see," p. 22. Nashville, 1840.

Black with mineralogical indications.

544.

**1842—Mitchell** (Dr.). Geological map of North Carolina.

Accompanying "A geological text book." (Raleigh) 1842.

A very small map. Not seen.

545.

**1843—Troost** (Gerard). Geological map of Davidson, Williams Maury Counties (Tennessee).

Accompanying "Seventh geological report to the general assembl nessee." Nashville, 1844.

A very rare map.

546.

**1845—Tuomey** (Michael). Geological map of South Carolina.

Accompanying "Report on the geology of South Carolina." 4°. C 1848.

547.

**[illegible]—Tuomey** (Michael). Geological map of Alabama.

Accompanying "First biennial report of the geology of Alabama." Tuskaloosa, 1850.

It is the rarest geological map of the New World, only 5 or 6 copies are known to exist. I possess one given by the author to D'Archiac.

548.

**[illegible]—White** (G.). Bonner's map of the State of Georgia, with the addition of its geological features. Scale, 20 miles to an inch.

Accompanying "Statistics of the State of Georgia." Savannah, 1849.

549.

**51—Safford** (J. M.) The Silurian Basin of Middle Tennessee.

Accompanying "The Silurian Basin of Middle Tennessee, with notices of the strata surrounding it." Amer. Journ. Silliman, Vol. XII, Nov. 1851, p. 352. New Haven, 1851.

Black with numbers and signs.

550.

**1—Tuomey** (Michael). Plan, or horizontal section showing the geological structure of Anthony's Creek Reservoir.

Accompanying "Report addressed to Hon. G. Y. Mason, president of the James River and Kanawha Canal Co.", November 6, 1851. (Richmond, Virginia, 1852).

Not seen.

551.

**[illegible]—Lieber** (O. M.). Geological map of Mississippi.

Accompanying "A sketch of the geology of the State of Mississippi." The Mining Magazine, edited by W. J. Tenney. Vol. III, p. 42. New York, July, 1854.

Black etching and geological indications.

552.

**5—Tuomey** (Michael). Geological map of the State of Alabama.

Accompanying "Second biennial report of the geology of Alabama," edited by J. W. Mallet. Montgomery, 1858.

This second edition of the geological map of Tuomey is also rare, and in some respects inferior to the first edition. The scale is smaller. Tuomey died in March, 1857, and the map was printed in New York by J. H. Colton without his supervision. However, it contains some corrections brought about by Tuomey's survey and explorations of the years 1854 and 1855. It is the first geological map colored by chromo-lithography in America.

553.

**56—Emmons** (Ebenetzer). Map of the Deep River coal field, North Carolina.

Accompanying "Geological report of the midland counties of North Carolina." Raleigh, 1856.

554.

**1856—Lieber** (O. M.). Geognostic map of York district. Scale, 5 to an inch.

Accompanying "Reports on the geognostic survey of South Carolina, 1860." First annual report. Plate IX. Columbia, 1856.

A second edition was published in 1858—No. 568.

555.

**1856—Lieber** (O. M.). Geognostic map of Chester district. Sc miles to an inch.

Accompanying "Reports on the geognostic survey of South Carolina 1860." First annual report. Plate VIII. Columbia, 1856.

A second edition was published in 1858—No. 569.

556.

**1856—Lieber** (O. M.). Geognostic map of Lancaster district.

Accompanying "Reports on the geognostic survey of South Carolina 1860." First annual report. Plate VII. Columbia, 1856.

A second edition was published in 1858—No. 570.

557.

**1856—Lieber** (O. M.). Geognostic map of Chesterfield district. 5 miles to an inch.

Accompanying "Reports on the geognostic survey of South Carolina 1860." First annual report. Plate VI. Columbia, 1856.

A second edition was published in 1858—No. 571.

These maps and reports are quite scarce, most of them having been in the fire that destroyed Columbia in 1865.

558.

**1856—Safford** (J. M.). Geological map of the State of Tennessee.

Accompanying "A geological reconnoissance of the State of Tenn being the author's first biennial report. Nashville, 1856.

559.

**1857—Harper** (L.). Geological chart of Mississippi.

Accompanying "Preliminary report on the geology and agriculture State of Mississippi." Jackson, 1857.

560.

**1857—Harper** (L.). Mississippi bottom in the State of Mississi the alluvial plains of the Mississippi River in Mississippi.

Accompanying "Preliminary report on the geology and agriculture State of Mississippi," p. 259. Jackson, 1857.

561.

**1857—Harper** (L.). Special map of Tishamingo County.

Accompanying "Preliminary report on the geology and agricultur State of Mississippi." Table IV. Jackson, 1857.

562.

57—**Harper** (L.). The prairies above Tibby Creek.
Accompanying "Preliminary report on the geology and agriculture of the State of Mississippi." Table V. Jackson, 1857.

563.

57—**Harper** (L.). Special map of Pontotoc County.
Accompanying "Preliminary report on the geology and agriculture of the State of Mississippi." Table VI. Jackson, 1857.

564.

57—**Harper** (L.). Special map of Tippah County.
Accompanying "Preliminary report on the geology and agriculture of the State of Mississippi." Table VII. Jackson, 1857.

565.

57—**Lieber** (O. M.).. Geognostic map of Union district. Scale, 5 miles to an inch.
Accompanying "Reports on the geognostic survey of South Carolina, 1856-1860." Second annual report. Plate XIII. Columbia, 1858.

566.

57—**Lieber** (O. M.). Geognostic map of the itacolumite, iron, and limestone region of Union, Spartanburgh, and York district, South Carolina. Scale, 1 inch to 2 miles and 1 inch to 1 mile.
Accompanying "Reports on the geognostic survey of South Carolina, 1856-1860." Second annual report. Plate XII. Columbia, 1858.
Two maps on the same plate, with different scales.

567.

57—**Lieber** (O. M.). Geognostic map of Spartanburgh district. Scale, 5 miles to 1 inch.
Accompanying "Reports on the geognostic survey of South Carolina, 1856-1860." Second annual report. Plate XIV. Columbia, 1858.

568.

58—**Lieber** (O. M.). Geognostic map of York district. Scale, 5 miles to 1 inch.
Accompanying "Reports on the geognostic survey of South Carolina, 1856-1860." First annual report. Plate IX. Columbia, 1858.
Reprint of the map of 1856, which see.—No. 554.

569.

58—**Lieber** (O. M.). Geognostic map of Chester district. Scale, 5 miles to 1 inch.
Accompanying "Reports on the geognostic survey of South Carolina, 1856-1860." First annual report. Plate VIII. Columbia, 1858.
Reprint of the map of 1856, which see.—No. 555.

570.

**1858—Lieber** (O. M.). Geognostic map of Lancaster distric
Accompanying "Reports on the geognostic survey of South C
1860." First annual report. Plate VII. Columbia, 1858.
Reprint of the map of 1856, which see—No. 556.

571.

**1858—Lieber** (O. M.). Geognostic map of Chesterfield dist
5 miles to 1 inch.
Accompanying "Reports on the geognostic survey of South C
1860." First annual report. Plate VI. Columbia, 1858.
Reprint of the map of 1856, which see—No. 557.

572.

**1859—Currey** (R. O.). A geological map of the copper regi
in the counties of Floyd, Carroll, and Grayson, Va
and Alleghany, N. C. Scale, 6¼ miles to 1 inch.
Accompanying "The copper and iron region of the Floyd-C
Plateau of the Blue Ridge in Virginia." "The Virginias," Vol
Staunton, Virginia, 1880.
Black etching, with geological inscriptions.

573.

**1859—Lieber** (O. M.). Geognostic map of Greenville distri
miles to 1 inch.
Accompanying "Reports on the geognostic survey of South C
1860." Plate XVI. Columbia, 1859.

574.

**1859—Lieber** (O. M.). Geognostic map of Pickens distri
miles to 1 inch.
Accompanying "Reports on the geognostic survey of South
1860." Plate XVII. Columbia, 1859.

575.

**1860—Hilgard** (E. W.). Geological map of Mississippi.
Accompanying "Report on the geology and agriculture of th
sissippi." Jackson, Mississippi, 1860.

576.

**1860—Lieber** (O. M.). Portion of Abbeville district arour
Mill. Scale, two and one-half miles to an inch.
Accompanying "Reports on the geognostic survey of South C
1860." Plate XX. Columbia, 1860.

577.

**1860—Lieber** (O. M.). Industrial map of South Carol
1:1,800,000.
Accompanying "Reports on the geognostic survey of South C
1860." Plate XXI. Columbia, 1860.

578.

**Lieber** (O. M.). Geognostic map of Anderson district. Scale, five miles to an inch.

Accompanying "Reports on the geognostic survey of South Carolina, 1856–1860." Plate XIX. Columbia, 1860.

579.

**Lieber** (O. M.). Geognostic map of Abbeville district.

Accompanying "Reports on the geognostic survey of South Carolina, 1856–1860." Plate XX. Columbia, 1860.

580.

**Safford** (J. M.). No title.

Accompanying "On the cretaceous and superior formations of West Tennessee." Amer. Journ, Silliman. 2d series, Vol. XXXVII, p. 362. New Haven, 1864.

Black etching, with numbers corresponding to geological indications in the text.

581.

**Sayler** (Nelson). Geological map of Kentucky. Geological formations delineated by Nelson Sayler. Scale, 5 miles to 1 inch. Cincinnati, 1865.

582.

**Sayler** (Nelson). Geological map of Tennessee. Scale, 5 miles to 1 inch. Cincinnati, 1865.

Not seen.

583.

**Lyman** (B. S.). A geological and topographical map of a rough survey of the Staley's Creek and Nick's Creek iron region near Marion, Smyth County, Virginia.

Accompanying "The Staley's Creek and Nick's Creek iron ore region." Trans. Amer. Phil. Soc. New series. 4°. Vol. XV, Article III, Plate II. Philadelphia, 1881.

Black etching, with geological indications.

584.

**Safford** (J. M.). Geological map of Tennessee. Scale, 12 miles to an inch.

Accompanying "Geology of Tennessee." Nashville, 1869.

585.

**Lesley** (J. P.). No title. Scale, 5 miles to one inch.

Accompanying "The geological structure of Tazewell, Russell, and Wise Counties, in Virginia." Proc. Amer. Phil. Soc., Vol. XII. Philadelphia, 1873.

586.

**1871—Lesley** (J. P.). Coal beds on Russell's Creek. Scale, 480 yards to 1 inch. Contour lines, 10 feet vertical apart. Foot survey by J. P. Lesley, October, 1870, Russell County, Virginia.

Accompanying "The geological structure of Tazewell, Russell, and Wise Counties, in Virginia." Proc. Amer. Phil. Soc., Vol. XII, p. 495. Philadelphia, 1873.

Black, with lithological and mineralogical indications.

587.

**1871—Lesley** (J. P.). Sketch map of Clinch River where it strikes the coal measures and rebounds at Lick Run.

Accompanying "The geological structure of Tazewell, Russell, and Wise Counties, in Virginia." Proc. Amer. Phil. Soc., Vol. XII, p. 497. Philadelphia, 1873.

Small black sketch, with mineralogical indications.

588.

**1871—Lesley** (J. P.). No title. (Sketch map part of Clinch River near Middle Creek.)

Accompanying "The geological structure of Tazewell, Russell, and Wise Counties, in Virginia." Proc. Amer. Phil. Soc., Vol. XII, p. 498. Philadelphia, 1873.

Small black sketch, with mineralogical indications.

589.

**1871—Lesley** (J. P.). No title. (Sketch map part of Clinch River above Middle Creek.)

Accompanying "The geological structure of Tazewell, Russell, and Wise Counties, in Virginia." Proc. Amer. Phil. Soc., Vol. XII, p. 502. Philadelphia, 1873.

Small black sketch, with mineralogical indications.

590.

**1871—Lesley** (J. P.). Local map of Abb's Valley coal, properly blue stone coal. Scale, 500 feet to 1 inch.

Accompanying "The geological structure of Tazewell, Russell, and Wise Counties in Virginia." Proc. Amer. Phil. Soc., Vol. XII, p. 505. Philadelphia, 1873.

Black, with lithological inscriptions.

591.

**1873—Lesley** (Joseph, jr.). Map of Eastern Kentucky, showing the western outcrop of its coal-field, as determined by surveys in 1858 and 1859. Scale, 12 miles to $\frac{1}{16}$ of an inch.

Accompanying "The outcrop belt of the Eastern Kentucky coal-field." Proc. Amer. Phil. Soc., Vol. XIII, p. 270. Philadelphia, 1873.

Black etching.

See **Lesley** (Joseph, jr.)—No. 598.

592.

74—**Rogers** (W. B.) and **Hotchkiss** (Jed.). Map of Virginia, by J. Hotchkiss. The geology by Prof. W. B. Rogers, chiefly from the State survey 1835–'41, "With later observations in some parts."

Accompanying "Virginia: a geographical and political summary," &c., p. 46. Richmond, 1876.

This map, with some additions, also appeared with the title: "**Hotchkiss's** geological map of Virginia and West Virginia. The geology by Prof. W. B. **Rogers**, chiefly from the Virginia State survey 1835–1841, with later observations in some parts." Scale, 1:1,520,640, or 24 miles to one inch. Accompanying "Preliminary report concerning the resources of the country adjacent to the line of the proposed Richmond and Southwestern Railway," by N. S. **Shaler**, Cambridge, 1880, and also in the "Virginias," Vol. I, No. 6, p. 92. Staunton, Va., 1880—No. 611.

593.

75—**Kerr** (W. C.). Geological map of North Carolina.

Accompanying "Report of the geological survey of North Carolina," Vol. I. Raleigh, 1875.

594.

75—**Shaler** (N. S.). Kentucky geological survey; preliminary map.

Accompanying "Report of progress," Vol. II. New series. Frankfort, 1877. Black etching.

See **Shaler** (N. S.)—Nos. 596, 599, 600, 613.

595.

76—**Stevenson** (J. J.). Sketch map to illustrate notes on the geology of West Virginia.

Accompanying "Notes on the geology of West Virginia." Proc. Amer. Phil. Soc., Vol. XIV, p. 370. Philadelphia, 1876.

Black; the double dotted line represents the eastern outcrop of the Pittsburgh coal.

596.

76—**Shaler** (N. S.) Kentucky geological survey. Preliminary map.

Accompanying "A general account of the commonwealth of Kentucky." Frankfort, 1876.

This pamphlet was compiled for distribution at the Centennial Exposition; a thousand copies of the map colored were issued, and later some additional copies with the map in black etching.

See **Shaler** (N. S.)—Nos. 594, 599, 600, 613.

597.

76—**Smith** (E. A.). Map showing the Southwest termination of the Coosa coal field.

Accompanying "Geological survey of Alabama." Report of progress for 1876. Montgomery, Ala., 1876.

Black etching.

598.

**1877—Lesley** (Joseph, jr.). Map of Eastern Kentucky, showing th ern outcrop of its coal field as determined by surveys ( and 1859.

Accompanying "Geological survey of Kentucky," Vol. III. Ne Frankfort, 1877.

See **Lesley** (Joseph, jr.)—No. 591.

599.

**1877—Shaler** (N. S.). Kentucky geological survey. Preliminai

Accompanying "The report of the Kentucky commissioner of ag for 1877." Frankfort, 1877.

Black etching. This is the map already mentioned published in v ports in colors or black etching.

See **Shaler** (N. S.) 1875,' 76–1880—Nos. 594, 596, 600, 613.

600.

**1877—Shaler** (N. S.). Kentucky geological survey, prelimina compiled from various surveys.

Accompanying "Geological survey of Kentucky," Vol. III. Ne Frankfort, 1877.

It appeared also in "Preliminary report concerning the resourc country adjacent to the line of the proposed Richmond and Soutl Railway," by N. S. **Shaler**. Cambridge, 1880.

See **Shaler** (N. S.)—Nos. 594, 596, 599, 613.

601.

**1878—Heinrich** (O. J.). Map of the eastern part of the State ginia. Scale, 20 miles to 1 inch.

Accompanying "The mesozoic formation in Virginia." Trans. An Mining Engrs., Vol. VI. Plate V. Easton, Pa., 1879.

Black etching and signs. The map and memoir have been rep "The Virginias" of Major Jed. **Hotchkiss**, Vol. I., No. 8, pages 124 Staunton, Va., August, 1880.

602.

**1878—Smith** (E. A.). Geological map of Alabama, prepared f ney's Hand-book of Alabama.

Accompanying "Hand-book of Alabama." A complete index to t with a geological map and an appendix of useful tables, by Saffold Mobile, 1878.

603.

**1878—Smith** (E. A.). Geological map of Marion County (Al Scale, 4 miles to 1 inch.

Accompanying "Geological survey of Alabama." Report of pr 1877 and 1878, p. 120. Montgomery, 1879.

604.

**1878—Smith** (E. A.). Geological map of Walker County (Al Scale, 4 miles to 1 inch.

Accompanying "Geological survey of Alabama." Report of pr 1877 and 1878, p. 82. Montgomery, 1879.

605.

**1878—Smith** (E. A.). Geological map of Winston County (Alabama). Scale, 4 miles to 1 inch.

Accompanying "Geological survey of Alabama." Report of progress for 1877 and 1878, p. 97. Montgomery, 1879.

606.

**1878—Smith** (A. E.). Geological map of Fayette County (Alabama). Scale, 4 miles to 1 inch.

Accompanying "Geological survey of Alabama." Report of progress for 1877 and 1878, p. 105. Montgomery, 1879.

607.

**1879—Smith** (E. A.). Map of the Black Warrior River from Tuscaloosa to the fork of Sipsey and Mulberry. Scale, 2 miles to 1 inch.

Accompanying "Geological survey of Alabama." Report of progress for 1879 and 1880. Montgomery, 1881.

608.

**1880—Hotchkiss** (Jed.). Map of the great Ohio Coal Basin, compiled from State geological surveys.

Accompanying "The coal fields of West Virginia and Virginia in the Great Ohio or Trans-Apalachian Coal Basin." "The Virginias." Vol. I, 4°, p. 188. Staunton, Virginia, 1880.

609.

**1880—Stevenson** (J. J.). Geological map of parts of Lee, Wise, Scott, and Washington Counties, Virginia. Scale, 5 miles to 1 inch.

Accompanying "A geological reconnaissance of parts of Lee, Wise, &c. Counties." Proc. Amer. Phil. Soc., Vol. XIX. No. 108, p. 219. Philadelphia, 1881.

The map and memoir have been reproduced in "The Virginias," Vol. II, p. 22. February, 1881. 4°. Staunton, Virginia, 1881.

610.

**1880—Heinrich** (O. J.). Map of the eastern part of the State of Virginia. Scale, 20 miles to 1 inch.

Accompanying "The Virginias," Vol. I, No. 8, pp. 124 and 125. Staunton, 1880.

See **Heinrich** (O. J.), 1878—No. 601.

611.

**1880—Rogers** (W. B.). Hotchkiss' geological map of Virginia and West Virginia. The geology by Prof. W. B. Rogers, chiefly from the Virginia State survey 1835–1841, with later observations in some parts. Scale, 1:1,520,640, or 24 miles to 1 inch.

Accompanying "Preliminary report concerning the resources of the country adjacent to the line of the proposed Richmond and Southwestern Railway," by N. S. Shaler. Cambridge, 1880.

See **Rogers** (W. B.), 1874—Nos. 592, 612.

612.

**1880—Rogers** (W. B.). (The same map as above.)
Accompanying "The Virginias," Vol. I, No. 6, p. 92. Staunton, 1880.
See **Rogers** (W. B.), 1874—Nos. 592, 611.

613.

**1881—Shaler** (N. S.). Kentucky geological survey, preliminary map compiled from various surveys.
Accompanying "Preliminary report concerning the resources of the country adjacent to the line of the proposed Richmond and Southwestern Railway," by N. S. Shaler. Cambridge, 1880.
See **Shaler** (N. S.), 1877—Nos. 594, 596, 599, 600.

614.

**1881—Hotchkiss** (Jed.). Centennial geological map of the Virginias. The geology that of the Virginia State survey, by Prof. W. B. Rogers, 1835–41, corrected by later observers. Scale, 3½ miles to 1 inch. Staunton, Va., 1881.
A very large wall map in 14 sheets.

615.

**1881—Smith** (E. A.). Geological map of Florida.
Accompanying "On the geology of Florida." Amer. Journ. Silliman, 3d series, Vol. XXI, p. 305. New Haven, 1881.
In black etching, with geological indications.

616.

**1881—Stevenson** (J. J.). Geological map of parts of Lee, Wise, Scott, and Washington Counties, Virginia. Scale, 5 miles to the inch.
Accompanying "A geological reconnaissance of parts of Lee, Wise, &c." The Virginias. Vol. II, p. 22, February number, 4°. Staunton, 1881.
See **Stevenson** (J. J.), 1880—No. 609.

## II—NORTHWESTERN STATES AND TERRITORIES, COMPRISING NEBRASKA, DAKOTA, WYOMING, MONTANA, NATIONAL PARK, AND IDAHO.

617.

**2—Evans** (John). Map showing the positions of the Bad Lands or Mauvaises Terres of Nebraska.

Accompanying "The ancient fauna of Nebraska," by Joseph Leidy, in Smithsonian contribution to knowledge, Vol. VI. 4°. Washington, 1852.

Black, with geological indications. It also appeared in illustrations of the geological survey of Wisconsin, Iowa, and Minnesota, by D. D. Owen. 4to. Philadelphia, 1852.

See **Evans** (John), 1852—No. 618.

618.

**2—Evans** (John). Map showing the position of the Bad Lands or Mauvaises Terres of Nebraska.

Accompanying "Report of a geological survey of Wisconsin, Iowa, and Minnesota, and incidentally of a portion of Nebraska Territory," by D. D. Owen, Vol. of illustrations. 4°. Philadelphia, 1852.

Black, with geological indications; the same as the map cited above.

See **Evans** (John), 1852—No. 617.

619.

**7—Hayden** (F. V.). Geology. Map of Nebraska.

Accompanying "Notes explanatory of a map and section illustrating the geological structure of the country bordering on the Missouri River, from the mouth of the Platte River to Fort Benton." Proc. Acad. Nat. Sciences, May, 1857. Philadelphia, 1857.

620.

**8—Hayden** (F. V.). Geology. Map of Nebraska.

Accompanying "Explanations of a second edition of a geological map of Nebraska and Kansas," based upon information obtained in an expedition to the Black Hills, under the command of G. K. Warren. Proc. Acad. Nat. Sciences, June, 1858. Philadelphia, 1858.

Important geological map for the Upper Missouri region. Reprinted in black etching, in Petermann's Geographische Mittheilungen. 4°. Vol. VI, p. 53. Gotha. 1860.

621.

**1859—Hayden** (F. V.). No title.

Accompanying "Geological sketch of the estuary and fresh water deposit of the bad lands of the Judith River." Trans. Amer. Phil. Soc. 4°. Vol. XI. New series, article XII. Plate VIII, p. 154. Philadelphia, 1860.

Outline map, with geological indications, of the Upper Missouri River region around Fort Benton.

622.

**1860—Hayden** (F. V.). Geologische Skizze der Black Hills, nach Hayden's Karte von A. Peterman. Scale, 1 : 6,500,000.

Accompanying "Petermann's Geographische Mittheilungen." 4°. Vol. VI, p. 53. Gotha, 1860.

Black etching.

See **Hayden** (F. V.), 1858—No. 620.

623.

**1862—Hayden** (F. V.). Outline reduction of the maps of Kansas, Nebraska, and Dakota. Geology.

Accompanying "On the geology and natural history of the Upper Missouri." Being the substance of a report made to Lieut. G. K. Warren. Trans. Amer. Phil. Soc. Vol. XII. 4to. Philadelphia, 1862.

624.

**1863—Marcou** (Jules). Carte géologique de la partie des bords du Missouri entre Omaha City et Sioux City, relevée en 1863.

Accompanying "Le terrain crétacé des environs de Sioux City, de la Mission des Omahas et de Tekama sur les bords du Missouri." Bull. Soc. Géol. France, 2e série. Vol. XXIV, p. 56. Paris, 1866.

Black etching.

625.

**1863—Marcou** (Jules). Carte géologique d'une partie de Nébraska; relevée en 1863.

Accompanying "Le Dyas au Nébraska," in Bull. Soc. Géol. France, 2e série. Vol. XXIV, p. 280. Paris, 1867.

Black etching.

626.

**1867—Hayden** (F. V.). Map of Nebraska and Dakota. Scale, 19 miles to inch.?

Accompanying "On the geology of the tertiary formations of Dakota and Nebraska." Journ. Acad. Nat. Sciences, 2d series, Vol. VII. Philadelphia, 1869.

627.

**1860—Hayden** (F. V.). Map of the Yellowstone and Missouri Rivers and their tributaries explored by Capt. W. F. Reynolds and Lieut. H. E. Maynadier, 1859, 1860. Scale, 1 : 1,200,000. Prepared to accompany the Geological Report of F. V. Hayden, M. D., Geologist to the Expedition.

Accompanying "Geological report of the exploration of the Yellowstone and Missouri rivers" by Dr. F. V. Hayden, assistant. Washington, 1869.

628.

72—**Hayden** (F. V.). Map of Nebraska and Dakota, and portions of the States and Territories bordering thereon, compiled by G. K. Warren. Geology by F. V. Hayden. Scale, 1:1,200,000.

Accompanying "Final report of the U. S. geological survey of Nebraska." Washington, 1872.

There is an error in the coloring by a transfer of the colors used for the granitic and metamorphic to the Potsdam sandstone and *vice versa*.

629.

72—**Hayden** (F. V.) and **Peale** (A. C.). Montana and Wyoming Territories, embracing most of the country drained by the Madison, Gallatin, and Upper Yellowstone River. Scale, four miles to an inch.

U. S. Geol. Surv. of the Territories. folio. (Washington, 1872.)
No place of publication nor date.

630.

73—**Hayden** (F. V.) and **Bradley** (F. H.). Map of the sources of Snake River with its tributaries, together with portions of the headwaters of the Madison and Yellowstone. Scale, five miles to one inch.

U. S. Geol. Surv. of the Territories. folio. (Washington, 1872.)
No place of publication nor date.

631.

74—**Comstock** (T. B.). Geological map of Western Wyoming, explored in 1873 by Capt. W. A. Jones. Scale, 1:600,000.

Accompanying "Report upon the reconnaissance of Northwestern Wyoming, including Yellowstone National Park, made in the summer of 1873." Washington, 1875.

632.

75—**Winchell** (N. H.). A geological map of the Black Hills. Scale, 6 miles to 1 inch.

Accompanying "Report of a reconnaissance of the Black Hills of Dakota, made in the summer of 1874," by Capt. William Ludlow. 4to. Washington, 1875.

633.

76—**Dana** (E. S.) and **Bird** (G. G.). No title. (Cut representing the vicinity of Camp Baker, Upper Missouri.)

Accompanying "Report of a reconnaissance from Carroll, Montana Territory, on the Upper Missouri, to the Yellowstone National Park, and return, made in the summer of 1875," by Capt. William Ludlow. Geological Report, p. 115, Fig. 9. 4to. Washington, 1876.

Black, with geological indications.

634.

**1876—Dana** (E. S.) and **Bird** (G. G.). No title. (Sketch of Little Rocky Mountains).

Accompanying "Report of a reconnaissance from Carroll, Montana Territory, on the Upper Missouri, to the Yellowstone National Park, and return, in the summer of 1875," by Capt. William Ludlow. Geological Report, p. 129, Fig. 14. 4to. Washington, 1876.

635.

**1876—King** (Clarence). Geological series. Map I. Rocky Mountains, Wyoming Territory, east half, west half. Scale, four miles to one inch.

Accompanying "Geological exploration of the fortieth parallel." Geological and topographical atlas, folio. New York, 1876.

In two sheets.

636.

**1876—King** (Clarence). Geological series. Map II. Green River Basin, Wyoming Territory. Scale, four miles to one inch.

Accompanying "Geological exploration of the fortieth parallel." Geological and topographical atlas, folio. New York, 1876.

In two sheets.

637.

**1879—Newton** (Henry). Geological map of the Black Hills of Dakota. Scale, 1 inch to 4 miles.

Accompanying "Report on the geology and resources of the Black Hills of Dakota." Topographical and geological atlas, folio. New York, 1879.

It is marked "Field work, 1875," and "Publication, 1879." Besides, the 4to volume of the report is marked "Washington, 1880." In fact, both atlas and volume did not appear and were not distributed to the public until 1881. Such discrepancies of date exist also for Clarence **King's** report and atlas, **J. W. Powell's** report and atlas, and F. V. **Hayden's** report and atlas.

## 7.—NORTHWEST TERRITORIES OF THE BRITISH POSSESSIONS, COMPRISING MANITOBA, HUDSON'S BAY COMPANY TERRITORY, SASKATCHEWAN RIVER OR ASSINNIBOINIA, BRITISH COLUMBIA, VANCOUVER AND QUEEN CHARLOTTE ISLANDS.

638.

**—Bigsby** (J. J.). Geological map of the Lake of the Woods, South Hudson's Bay.

Accompanying "On the geology of the Lake of the Woods, South Hudson's Bay." Journ. Geol. Soc. London, Vol. VIII, p. 400. London, 1852.

Black etching.

639.

**—Bigsby** (J. J.). Geological map of Rainy Lake.

Accompanying "On the geology of Rainy Lake, South Hudson's Bay." Journ. Geol. Soc. London, Vol. X, p. 215. London, 1854.

Black etching.

640.

**—Devine** (Thomas). Map of the northwest part of Canada, Indian Territory, and Hudson's Bay. Scale, English miles, 69–160 one degree. Toronto, 1857.

In four sheets.

641.

**—Hector** (James). Map of Winipeg Lake Basin. Showing the distribution of superficial deposits.

Accompanying "First general report on the geology of the country examined by the expedition under the command of John Palliser, esq., during the season of 1857." Map 8. In papers relative to the exploration of British North America. Blue Book. 4°. London, 1859.

642.

**—Hind** (H. Y.). Geological map of a part of Rupert's Land.

Accompanying "Narrative of the Canadian Red River exploring expedition of 1857, and of the Assinniboine and Saskatchewan exploring expedition of 1858;" in two volumes. Vol. II, p. 239. London, 1860.

643.

**—Hind** (H. Y.). Geological map of a portion of Rupert's Land.

Accompanying "Reports of progress on the Assinniboine and Saskatchewan exploring expedition." 4°. Blue Book. Toronto, 1859, and London, 1860.

The Toronto edition is on a much larger scale than the London one.

644.

**—Nicol** (C. S.) and **Hector** (James). Plan of Nanaimo, showing the coal mines. Scale, 1 furlong to ¼ inch.

Accompanying "Reports of Captain Palliser's exploration of that portion of British North America which in latitude lies between the British boundary line and the height of land or watershed of the northern or frozen ocean, respectively, and in longitude between the western shore of Lake Superior and the Pacific Ocean, during the years 1857–'58–'59, and '60." Index and maps. Blue Book. 4°. London, 1865.

645.

**1861—Hector** (James). Geological map of the country between Lake Superior and Vancouver Island.

Accompanying "On the geology of the country between Lake Superior and the Pacific Ocean, visited by the Government exploring expedition under the command of Capt. J. Palliser, 1857–1860." Journ. Geol. Soc., London, Vol. XVII. Plate XIII, p. 388. London, 1861.

Black etching, an important map; on the same plate there is also a geological sketch map of Nanaimo, Vancouver Island.

646.

**1861—Hector** (James). Geological sketch map of Nanaimo, Vancouver Island.

Accompanying "On the geology of the country between Lake Superior and the Pacific Ocean, visited by the Government exploring expedition under the command of Capt. J. Palliser, 1857–1860." Journ. Geol. Soc., London, Vol. XVII. Plate XIII, p. 388. London, 1861.

Black etching, on the same sheet as the map above it, which see.

See **Hector** (James), 1861—No. 645.

647.

**1865—Hector** (James). Geological sketch map of Nanaimo, in Vancouver Island. Scale, 1 inch to 1 mile.

Accompanying "Reports of Captain Palliser's exploration of that portion of British North America, which in latitude lies between the British boundary line and the height of land or watershed of the northern or frozen ocean, respectively, and in longitude between the western shore of Lake Superior and the Pacific Ocean, during the years 1857–'58–'59, and '60," &c. Index and maps. Blue Book. 4°. London, 1865.

648.

**1865—Hector** (James). Geological sketch of the southeast of Vancouver Island and part of the coast of the Gulf of Georgia.

Accompanying "Reports of Captain Palliser's exploration of that portion of British North America which in latitude lies between the British boundary line and the height of land or watershed of the northern or frozen ocean, respectively, and in longitude between the western shore of Lake Superior and the Pacific Ocean, during the years 1857–'58–'59, and '60." Index and maps. Blue Book. 4°. London, 1865.

649.

**1869—Macfarlane** (Thomas). Lithological map of Wood's location. Scale, 2,000 feet to 1 inch.

Accompanying "On the geology and silver ore of Wood's location, Thunder Cape, Lake Superior." The Canadian Naturalist and Geologist. New series Vol, IV, p. 377. Montreal, 1869.

650.

71—**Richardson** (James). Map showing the position of the coal fields of Nanaimo and Comox, Vancouver Island. Scale, 10 miles to 1 inch.

Accompanying Geol. Surv. Canada; report of progress for 1871–'72; "Report on the coal fields of the east coast of Vancouver Island," p. 100. Montreal, 1872.

Black etching.

651.

72—**Richardson** (James). Map of a part of the Strait of Georgia and of Vancouver Island, showing a portion of the Comox coal field and the distribution of the Cretaceous coal-bearing rocks. Scale, 2 miles to 1 inch.

Accompanying Geol. Surv. Canada; report of progress for 1872–'73; "Report on the coal fields of Vancouver and Queen Charlotte Islands," p. 64. Montreal, 1873.

Black etching.

652.

74—**Selwyn** (A. R. C.). Sketch survey of the Saskatchewan River from Rocky Mountain House to Cumberland Lake. Scale, 16 miles to 1 inch.

Accompanying Geol. Surv. Canada; report of progress for 1873–'74; "Observations in the Northwest Territory on a journey across the plains from Fort Garry to Rocky Mountain House, returning by the Saskatchewan River and Lake Winnipeg," 1873, p. 17. Montreal, 1874.

Black, with geological indications.

653.

75—**Dawson** (G. M.). Map of part of the interior region of North America, showing the general character of the drift.

Accompanying "On the superficial geology of the central region of North America." Journ. Geol. Soc., London, Vol. XXXI, p. 623. London, 1875.

Black etching.

654.

75—**Dawson** (G. M.). General geological map of the country in the vicinity of the forty-ninth parallel.

Accompanying British North American boundary commission. "Report on the geology and resources of the region in the vicinity of the forty-ninth parallel, from the Lake of the Woods to the Rocky Mountains." Montreal, 1875.

655.

75—**Dawson** (G. M.). Geological map of the Lake of the Woods.

Accompanying British North American Boundary Commission. "Report on the geology and resources of the region in the vicinity of the forty-ninth parallel." Montreal, 1875.

656.

75—**Dawson** (G. M.). Geological sketch map of the vicinity of Bay Portage, Lake of the Woods.

Accompanying British North American Boundary Commission. "Report on the geology and resources of the region in the vicinity of the forty-ninth parallel." Plate II, p. 46. Montreal, 1875.

Black etching.

657.

**1875—Nicholson** (H. A.). Sketch map of Lake Superior, &c.

Accompanying "On the mining districts on the north shore o Superior." Trans. North of England Inst. Mining Engrs., Vol. XXI XL. Newcastle-upon-Tyne, 1875.

658.

**1876—Dawson** (G. M.). Geological map of a portion of British Co between the Fraser River and the coast range.

Accompanying Geol. Surv. Canada; report of progress for 1876-'77; on explorations in British Columbia, chiefly in the basin of the Bla Salmon, and Nechacco Rivers, and on Francois Lake," p. 17. Montr

659.

**1877—Bell** (Robert). Map of part of the east coast of Hudson Scale, 4 miles to 1 inch.

Accompanying Geol. Surv. Canada; report of progress for 1877-'78; on an exploration of the east coast of Hudson's Bay." Atlas. Montr

Black, with geological indications.

660.

**1877—Richardson** (James). Map of a portion of British Columbia, s the coal fields of Comox, Nanaimo, and Cowitchin, on Van and adjacent islands, and the distribution of the Cretaceou bearing rocks, also the Tertiary rocks of Sooke and I inlet.

Accompanying Geol. Surv. Canada; report of progress for 1876-'77; on the coal fields of Nanaimo, Comox, Cowichen, Burrard Inlet, an British Columbia," p. 192. Montreal, 1878.

661.

**1877—Selwyn** (A. R. C.). Sketch survey of route from Quesnel by Stewart and MacLeod's Lakes, to the junction of Smok and Peace River.

Accompanying Geol. Surv. Canada; report of progress for 1875-'76; on exploration in British Columbia in 1875," p. 1. Montreal, 1877.

Black, with geological indications.

662.

**1878—Bell** (Robert). Map of Nelson River and the boat-route b Lake Winnipeg and Hudson's Bay, and map of Lake Wi Scale, 8 miles to 1 inch.

Accompanying Geol. Surv. Canada; report of progress for 1877-'78; on the country between Lake Winnipeg and Hudson's Bay, 1878." Montreal, 1879.

Black, with geological indications; in two sheets.

663.

1878—**Dawson** (G. M.). Map of the Queen Charlotte Islands. Scale 1:506,880.

Accompanying Geol. Surv. Canada; report of progress for 1878-'79; "Report on the Queen Charlotte Islands." Montreal, 1880.

Also in "Petermann's Geographische Mittheilungen." 4to. Vol. XXVII, 1881. Plate XVI. Gotha, 1881.

See **Dawson** (G. M.), 1881—No. 667.

664.

1878—**Richardson** (James) and **Dawson** (G. M.). Geological map of Skidegate Inlet, Queen Charlotte Islands.

Accompanying: Geol. Surv. Canada; report of progress for 1878-'79. "Report on the Queen Charlotte Islands;" p. 63, B. Montreal, 1880.

The part, by J. Richardson, was surveyed in 1872.

665.

179—**Bell** (Robert). Map of Island and God's Lakes, and of the connecting waters to Oxford Lake. Scale, 4 miles to 1 inch.

Accompanying Geol. Surv. Canada; report of progress for 1878-'79. "Report on explorations on the Churchill and Nelson Rivers and around God's and Island Lakes." Montreal, 1880.

Black, with geological indications.

666.

80—**Dawson** (G. M.). Map of part of British Columbia and the northwest territory from the Pacific Ocean to Fort Edmonton. Scale, 1:506,880.

Accompanying Geol. Surv. Canada; report of progress for 1879-'80. "Report on an exploration from Port Simpson on the Pacific coast, to Edmonton on the Saskatchewan, embracing a portion of the northern part of British Columbia, and the Peace River country." Atlas. Montreal, 1881.

Black, with geological indications, in three sheets.

667.

81—**Dawson** (G. M.). Geologische Karte der Queen Charlotte Islands. Scale, 1:1,100,000.

Accompanying "Petermann's Geographische Mittheilungen." 4°. Vol. XXVII. Plate XVI. Gotha, 1881.

See **Dawson** (G. M.), 1878—No. 663.

668.

881—**Dawson** (G. M.). Geological sketch map of British Columbia. Scale, 100 miles to ½ inch.

Accompanying "Sketch of the geology of British Columbia." The Geological Magazine, Vol. VIII, 2d series, p. 160. London, 1881.

Black etching.

## XV.—PACIFIC STATES AND TERRITORIES, COMPRISING ALASKA, WASHINGTON, OREGON, AND CALIFORNIA.

669.

**1849—Grewingk** (C.). Karte zur Abhandlung über die Geogn. u. orogr. Beschaffenheit der N. W.-Küste Amerika's, u. der anliegenden Inseln mit Zugrundelegung der Karten des Hydrogr. Dep. des See-Ministeriums zu St. Petersburg.

Accompanying "Beitrag zur Kenntniss der orographischen und geognostischen Beschaffenheit der Nord-West-Küste Amerika's, mit den anliegenden inseln." Verhandlungen der Russich-Kaiserlichen Mineralogischen Gesellschaft zu St. Petersburg. Jahrgang, 1848 und 1849, p. 76. Plate II. St Petersburg, 1850.

Grewingk did not visit Alaska, but constructed the geological map as wrote his memoir from notes taken on the spot by Ilia Wosnessensky, zoölogist of the Museum der Academie der Wissenschaften in St. Petersburg.

670.

**1850—Tyson** (P. T.). Geological reconnaissance in California.

Accompanying "Report of P. T. Tyson upon the geology of California Washington, 1850.

Black, with mineralogical indications.

671.

**1853—Blake** (W. P.). Geological map of the vicinity of San Francisco

Accompanying "Reports of explorations and surveys for a Railroad rou from the Mississippi River to the Pacific Ocean." Vol. V, p. 145. 4°. Wash ington, 1856.

This map should more exactly be called a mineralogical map.

672.

**1855—Blake** (W. P.). Geological map of the entrance to San Francisco Bay. Scale, 1:150,000.

Accompanying "Physical geography and geology of the coast of Califo nia, from Bodega Bay to San Diego." In Report of the Superintendent of the Coast Survey during the year 1855; 4°. p. 376. Washington, 1856.

Black etching.

673.

**1855—Blake** (W. P.). Geological map and section of Punta de Los Reyes. Scale, 1:150,000.

Accompanying "Physical geography and geology of the coast of Califo nia, from Bodega Bay to San Diego." In Report of the Superintendent of the Coast Survey during the year 1855; 4°. p. 376. Washington, 1856.

Black etching.

674.

55—**Blake** (W. P.). Geological map of San Diego and the adjoining coast. Scale, 1:608,228.

Accompanying "Physical geography and geology of the coast of California, from Bodega Bay to San Diego." In Report of the Superintendent of the U. S. Coast Survey during the year 1855; 4°. p. 376. Washington, 1856.

Black etching.

675.

55—**Blake** (W. P.). Geological map of Point Pinos, and Monterey Bay. Scale, 1:150,000.

Accompanying "Physical geography and geology of the coast of California, from Bodega Bay to San Diego." In Report of the Superintendent of the Coast Survey during the year 1855; in 4°. p. 376. Washington, 1856.

Black etching.

676.

5—**Blake** (W. P.). Geological map of the country between San Diego and the Colorado River, California. Scale, 1:608,228.

Accompanying "Reports of explorations and surveys for a Railroad route from the Mississippi River to the Pacific Ocean." Vol. V. p. 228. 4°. Washington, 1856.

677.

3—**Antisell** (Thomas). Geological plan of the Coast Range of California from San Francisco Bay to Los Angeles, explored in 1855–'56 by Lieut. John G. Parke. Scale, 1:1,570,640, or 24 miles to 1 inch.

Accompanying "Reports of explorations and surveys for a Railroad route from the Mississippi River to the Pacific Ocean." Vol. VII. p. 266. 4°. Washington, 1857.

678.

8—**Blake** (W. P.). Geological map of a part of the State of California explored in 1853 by Lieut. R. S. Williamson.

Accompanying "Reports of explorations and surveys for a Railroad route from the Mississippi River to the Pacific Ocean." Vol. V. 4°. Washington, 1856.

679.

6—**Blake** (W. P.). Geological map of the Tejon Pass and Cañada de las Uvas and the vicinity. Including the Pass of San Francisquito and Williamson's Pass.

Accompanying "Reports of explorations and surveys for a Railroad route from the Mississippi River to the Pacific Ocean." Vol. V. p. 197. 4°. Washington, 1856.

680.

**1861—Rémond** (A.). [Auguste Rémond de Corbineau.] No
Accompanying "Report of an exploration and survey of the Monte Diablo district" (California.) San Francisco, 1861.
Small sketch map in black showing tertiary hills.

681.

**1873—Bowman** (A.), **Pettee** (W. H.), and **Goodyear** (W. A.). Tertiary auriferous gravel deposits lying between the r of the American and the middle Yuba rivers. Scale the inch.
Accompanying "The auriferous gravels of the Sierra Nevada o by J. D. Whitney. In Mem. Mus. Comp. Zoöl. at Cambridge, M No. 1 (1st part) and (2nd part). 4°. Cambridge, 1880.
In two sheets. East half, corrected and revised, to replace th same sheet given in Part I. So the book contains two copies of sheet.
It is not exactly a geological map, showing only the "v flows." The other indications are purely economical. These re to the other auriferous gravels maps by J. D. Whitney.

682.

**1875—Marcou** (Jules). Carte géologique de la Californie, Scale $\frac{1}{6.000.000}$.
Accompanying "Note sur la Géologie de la Californie." Bu France, 3ème série, Tome XI, Plate XI, p. 407. Paris, 1883.
The publication of this map was unavoidably delayed.

683.

**1876—Hendel** (C. W.). Map of the region near Gibsonvi 1,200 feet to the inch.
Accompanying "The auriferous gravels of the Sierra Nevada o by J. D. Whitney. Mem. Mus. Comp. Zoöl. at Cambridge, Ma 4°. No. 1. Plate T, p. 450. Cambridge, 1880.

684.

**1877—Bowie** (A. J., jr.). Surroundings of River Tunnel, estate, 1877, California.
Accompanying "Hydraulic mining in California." Trans. Am ing Engrs. Vol. VI, Plate I, Fig. 6. Easton, Pa., 1879.
Black etching and lithological indications.

685.

**1877—Bowie** (A. J., jr.). Map of "River Tunnel" on Marip showing the course of vein and workings up to Aug. 1
Accompanying "Hydraulic mining in California." Trans. Am ing Engrs. Vol. VI, Plate I, Fig. 1. Easton, Pa., 1879.
Black etching, and lithological indications.

686.

879—**Pettee** (W. H.) and **Bowman** (A.). Map showing the extent of the hydraulic mining operations near Gold Run, Dutch Flat, Little York, You Bet, Chalk Bluffs, Red Dog, Hunt's Hill, and Quaker Hill, on Bear River and Cañon, Steep Hollow, and Greenhorn Creeks. Scale, 4 inches to 1 mile.

Accompanying "The auriferous gravels of the Sierra Nevada of California," by J. D. Whitney. In Mem. Mus. Comp. Zoöl. at Cambridge, Mass. Vol. VI. 4°. No. 1. Cambridge, 1880.

687.

880—**Bowman** (A.). Map of the Smartsville gravels. Scale, 1 mile to 7 inches.

Accompanying "The auriferous gravels of the Sierra Nevada, of California," by J. D. Whitney. In Mem. Comp. Zoöl. at Cambridge, Mass. Vol. VI. 4°. No. 1. Plate M., p. 380. Cambridge, 1880.

688.

881—**Whitney** (J. D.). Diagram showing the position of the Table Mountain lava flow of Tuolumne County. Scale, 2 miles to the inch.

Accompanying "The auriferous gravels of the Sierra Nevada of California." In Mem. Mus. Comp. Zoöl. at Cambridge, Mass. Vol. VI. 4°. No. 1. Plate D, p. 132. Cambridge, 1880.

689.

882—**Whitney** (J. D.). Plan of Spanish Peak gravel deposit.

Accompanying "The auriferous gravels of the Sierra Nevada of California." In Mem. Mus. Comp. Zoöl. at Cambridge, Mass. Vol. VI. 4°. No. 1. Plate K, p. 216. Cambridge, 1880.

Black, with lithological inscriptions.

690.

883—**Whitney** (J. D.). Map of the mining district adjacent to Forest City. Scale, 1 mile to the inch.

Accompanying "The auriferous gravels of the Sierra Nevada of California" In Mem. Mus. Comp. Zoöl. at Cambridge, Mass. Vol. VI. 4°. No. 1. Plate Q, p. 432. Cambridge, 1880.

691.

884—**Whitney** (J. D.). Map to accompany the description of a portion of the region drained by Slate, Cañon, and Goodyear Creeks in Sierra and Plumas Counties. Scale, 2 miles to 1 inch.

Accompanying "The auriferous gravels of the Sierra Nevada of California." In Mem. Mus. Comp. Zoöl. at Cambridge, Mass. Vol. VI. 4°. No. 1. Plate R, p. 444. Cambridge, 1880.

692.

1880—**Hendel** (C. W.). Map of Poverty Hill, Scales's diggings, and ity. Scale, 1½ inches to the mile.

Accompanying "The auriferous gravels of the Sierra Nevada of Cali by J. D. Whitney. In Mem. Mus. Com. Zoöl. at Cambridge, Mass. 4°. No. 1. Plate U, p. 452. Cambridge, 1880.

693.

1880—**Whitney** (J. D.). Sketch map, showing the distribution volcanic and gravel formations over a portion of Placer : Dorado Counties, California.

Accompanying "The auriferous gravels of the Sierra Nevada of Cal In Mem. Mus. Comp. Zoöl. at Cambridge, Mass. Vol. VI. 4°. No. 1 B, p. 82. Cambridge, 1880.

694.

1890—**Whitney** (J. D.). Distribution of the volcanic formatio gravel near Placerville. Scale, 1 mile = 1½ inches.

Accompanying. "The auriferous gravels of the Sierra Nevada of Cali In Mem. Mus. Comp. Zoöl. at Cambridge, Mass. Vol. VI. 4°. No. 1 C, p. 98. Cambridge, 1880.

695.

k (F. B.). Geological map of Moniteau County.
companying "The first and second annual reports of the geological sur-
of Missouri." Part II, p. 94. Jefferson City, 1855.

696.

mard (B. F.). Geological map of Franklin County.
companying "The first and second annual reports of the geological survey
issouri." Part II, p. 168. Jefferson City, 1855.
ack dotted lines and geological indications.

697.

mard (B. F.). Geological map of Saint Louis County.
companying "The first and second annual reports of the geological survey
issouri." Part II, p. 184. Jefferson City, 1855.

698.

llow (G. C.). Geological map of Marion County.
companying "The first and second annual reports of the geological survey
issouri." Part I, p. 178. Jefferson City, 1855.

699.

llow (G. C.). Geological map of Cooper County.
companying "The first and second annual reports of the geological survey
issouri." Part I, p. 202. Jefferson City, 1855.

700.

k (F. B.). Geological map of Miller County.
companying "Reports of the geological survey of Missouri, 1855–1871,"
0. Jefferson City, 1873.

701.

k (F. B.). Geological map of Morgan County.
companying "Reports of the geological survey of Missouri, 1855–1871,"
4. Jefferson City, 1873.

702.

lips (J. V.). Geological map, showing the mineral region
iguous to the Iron Mountain Railroad, Missouri. Scale, 2
es to 6 miles.
companying "Report on the geology of the mineral districts contiguous
e Iron Mountain Railroad." Saint Louis, 1859.

703.

**1859—Swallow** (G. C.). Geological map of Southwest Branch Pacific Railroad (Missouri).

Accompanying "Geological report of the country along the line of the Southwestern Branch of the Pacific Railroad, State of Missouri." Saint Louis, 1859.

704.

**1870—Emmons** (S. F.). Geological map of the Toyabe Mountains (Nevada).

Accompanying "Geological exploration of the fortieth parallel." Vol. III, 4°. Mining Industry. Atlas. Plate 13. New York, 1870.

705.

**1870—Hague** (Arnold). Geological map of the White Pine mining district (Nevada).

Accompanying "Geological exploration of the fortieth parallel." Vol. III, 4°. Mining Industry. Atlas. Plate 14. New York, 1870.

706.

**1870—King** (Clarence). Geological map of the Washoe mining district Nevada. Scale, 3 inches to 1 mile.

Accompanying "Geological exploration of the fortieth parallel." Vol. III, 4°. Mining Industry. Atlas. Plate 2. New York, 1870.

707.

**1872—Pumpelly** (Raphael). Magnetic geological map of the Pilot Knob iron district.

Accompanying "Geological survey of Missouri." Report on the iron ores and coal fields. Atlas. Plate II. New York, 1873.

708.

**1872—Swallow** (G. C.). Geological map of Missouri.

Accompanying "Geological sketch of the State of Missouri," illustrated maps. Extract from "Sectional, topographical, and descriptive atlas of State of Missouri," by R. A. Campbell. Folio. Saint Louis, 1873.

709.

**1873—Broadhead** (G. C.). Preliminary geological map of Northern Missouri.

Accompanying "Geological survey of Missouri." Report on the iron ores and coal fields. Atlas. Plate V. New York, 1873.

710.

**1873—Endlich** (F. M.). Geological map of the Central City mining region.

Accompanying "Report of the San Luis division (Colorado); in U. Geol. and Geogr. Surv. Territories." Explorations of 1873. Seventh annual report. Part I, p. 280. Washington, 1874.

Black etching.

711.

3—**Endlich** (F. M.). Geological map of the Mount Lincoln mining region.

Accompanying "Report of the San Luis division (Colorado); in U. S. Geol. and Geogr. Surv. Territories." Explorations of 1873. Seventh annual report. Part I, p. 302. Washington, 1874.

Black etching.

712.

3—**Marvine** (A. R.). Map of the coal openings, railroad, sections, &c., along the eastern base of the mountains near Denver City. Scale, 6 miles to an inch.

Accompanying "Report of the Middle Park Division (Colorado); in U. S. Geol. and Geogr. Surv. Territories." Explorations of 1873. Seventh annual report. Part I, p. 120. Washington, 1874.

Black etching.

713.

73—**Marvine** (A. R.). Geological map of the Middle Park.

Accompanying "Report of the Middle Park Division (Colorado); in U. S. Geol. and Geogr. Surv. Territories." Explorations of 1873. Seventh annual report. Part I, p. 154. Washington, 1874.

Black etching.

714.

73—**Marvine** (A. R.). Geological map of the region in the neighborhood of the Hot Springs and the Upper Grand; Middle Park.

Accompanying "Report of the Middle Park Division (Colorado); in U. S. Geol. and Geogr. Surv. Territories." Explorations of 1873. Seventh annual report. Part I, p. 162. Washington, 1874.

Black etching.

715.

73—**Potter** (W. B.). Geological map of Lincoln County (Missouri). Scale, 1 mile to 1 inch.

Accompanying "Geological survey of Missouri." Report on the iron ores and coal fields. Atlas. Plate VIII. New York, 1873.

716.

73—**Potter** (W. B.). Map of Lincoln County coal region (Missouri.)

Accompanying "Geological survey of Missouri." Report on the iron ores and coal fields. Atlas. Plate IX. New York, 1873.

717.

73—**Powell** (J. W.). Green River from the Union Pacific Railroad to the mouth of White River (Utah). Scale, 4 miles to 1 inch.

Accompanying "Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto." 4°. Atlas. Washington, 1876.

718.

**1873—Shumard** (B. F.). Geological map of Ozark County.
Accompanying "Geological survey of Missouri, 1855–1871," p. 188. Jefferson City, 1873.

719.

**1873—Shumard** (B. F.). Geological map of Wright County.
Accompanying "Geological survey of Missouri, 1855–1871," p. 205. Jefferson City, 1873.
Black, with geological indications.

720.

**1873—Shumard** (B. F.). Geological map of Pulaski County.
Accompanying "Geological survey of Missouri, 1855–1871," p. 224. Jefferson City, 1873.
Black, with geological indications.

721.

**1873—Shumard** (B. F.). Geological map of Cape Girardeau County.
Accompanying "Geological survey of Missouri, 1855–1871," p. 274. Jefferson City, 1873.
Black, with geological indications.

722.

**1873—Shumard** (B. F.). Geological map of Saint Geneviève County.
Accompanying "Geological survey of Missouri, 1855–1871," p. 290. Jefferson City, 1873.
Black, with dotted lines and geological indications.

723.

**1873—Shumard** (B. F.). Geological map of Jefferson County.
Accompanying "Geological survey of Missouri, 1855–1871," p. 304. Jefferson City, 1873.

724.

**1873—Shumard** (B. F.) Geological map of Clark County.
Accompanying "Geological survey of Missouri, 1855–1871," p. 314. Jefferson City, 1873.

725.

**1874—Broadhead** (G. C.) and **Schmidt** (A.). Missouri geological survey. Map of the lead region of Central Missouri.
Accompanying "Geological survey of Missouri, 1873–1874." Atlas, Jefferson City, 1874.
Black, with geological indications.

726.

**1874—Broadhead** and **Norwood**, assisted by **Schmidt** (A.) and **Leon** (A.). Geological map of Jasper County, with lead region Jasper and Newton Counties.
Accompanying "Geological survey of Missouri, 1873–1874." Atlas, Jefferson City, 1874.

727.

4—**Broadhead** (G. C.). Missouri geological survey. Cedar County.
Accompanying "Geological survey of Missouri, 1873–1874." Atlas, folio. Jefferson City, 1874.

728.

4—**Broadhead** (G. C.). Missouri geological survey. Barton County.
Accompanying "Geological survey of Missouri, 1873–1874." Atlas, folio. Jefferson City, 1874.

729.

4—**Broadhead** (G. C.). Missouri geological survey. Vernon County.
Accompanying "Geological survey of Missouri, 1873–1874." Atlas, folio. Jefferson City, 1874.

730.

4—**Broadhead** (G.C.) and **Norwood** (C. J.). Missouri geological survey. Howard County.
Accompanying "Geological survey of Missouri, 1873–1874." Atlas, folio. Jefferson City, 1874.

731.

4—**Broadhead** (G. C.) and **Norwood** (C. J.). Missouri geological survey. Part of Northern Missouri.
Accompanying "Geological survey of Missouri, 1873–1874." Atlas, folio. Jefferson City, 1874.
Black, with dotted lines and geological indications.

732.

4—**Broadhead** (G. C.) and **Norwood** (C.J.). Missouri geological survey. Madison County.
Accompanying "Geological survey of Missouri, 1873–1874." Atlas, folio. Jefferson City, 1874.

733.

74—**Hayden** (F. V.) and **Holmes** (W. H.). Geological map of Colorado Springs and vicinity, Colorado. Scale, 1 mile to 1 inch.
Accompanying U. S. Geol. and Geogr. Surv. Territories. Explorations of 1874. "Report of F. V. Hayden." Eighth annual report, p. 40. Washington, 1876.
Pink etching.

734.

74—**Hayden** (F. V.). Preliminary map of the eastern base of the Rocky Mountains, Colorado, from the Arkansas River to the Wyoming line, showing the limits of the sedimentary rocks, and also the coal outcrops. Scale, 4 miles to 1 inch.
Accompanying U. S. Geol. and Geogr. Surv. Territories. Explorations of 1874. "Report of F. V. Hayden." Eighth annual report, p. 41. Washington, 1876.
Black, with geological indications.

735.

**1874—Hayden (F. V.) and Holmes (W. H.). Map of the Elk Mountains, Colorado. Scale, 2 miles to 1 inch.**

Accompanying "Report on the geology of the northwestern portion of the Elk range." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1874. Eighth annual report, p. 72. Washington, 1876.

Blue etching.

736.

**1874—Peale (A. C.). Map A. Shewing lines of sections (on Eagle River).**

Accompanying "Report of middle division (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1874. Eighth annual report, p. 84. Washington, 1876.

Black etching.

737.

**1874—Peale (A. C.). Map B. Showing lines of section (across Gunnison River).**

Accompanying "Report of middle division (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1874. Eighth annual report, p. 100. Washington, 1876.

Black etching.

738.

**1874—Peale (A. C.). Map C. Showing areas of porphyritic trachyte (Elk Mountains).**

Accompanying "Report of middle division (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1874. Eighth annual report, p. 166. Washington, 1876.

739.

**1874—Peale (A. C.). Map D. Showing areas of rhyolite and breccia (across the Gunnison River).**

Accompanying "Report of middle division (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1874. Eighth annual report, p. 170. Washington, 1876.

Black etching.

740.

**1874—Peale (A. C.). Map E. Showing basaltic plateaus between the Grand and Gunnison Rivers.**

Accompanying "Report of middle division (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1874. Eighth annual report, p. 174. Washington, 1876.

Black etching.

741.

**1875—Endlich (F. M.). (Geological) Map of Baker's Park and vicinity, (Colorado).**

Accompanying "Report on the mines and geology of the San Juan Country." In Bulletin of the U. S. Geol. and Geogr. Surv. Territories. Vol. I, No. 3, second series, p. 164. Washington, 1875.

Black etching.

742.

75—**Endlich** (F. M.). Map of Spanish Peaks region.

Accompanying "Geological report on the southeastern district (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1875. Ninth annual report, p. 132. Washington, 1877.

Black etching.

743.

75—**Endlich** (F. M.). Map of Trinidad region.

Accompanying "Geological report on the southeastern district (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1875. Ninth annual report, p. 196. Washington, 1877.

Black etching.

744.

75—**Peale** (A. C.). Map of south side of Gunnison River.

Accompanying "Geological report on the Grand River district (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1875 Ninth annual report, p. 38. Washington, 1877.

Black etching.

745.

75—**Peale** (A. C.). Map of Unaweep Cañon, Colorado.

Accompanying "Geological report on the Grand River district (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1875. Ninth annual report," p. 58. Washington, 1877.

Black etching.

746.

76—**Gilbert** (G. K.), **Marvine** (A. R.), and **Howell** (E. E.). Parts of Eastern California, Southeastern Nevada, Northwestern Arizona, and Southwestern Utah. Scale, 1 inch to 8 miles, or 1:506,880.

Accompanying "Geological atlas projected to illustrate United States geographical surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." New York, 1876.

747.

76—**Gilbert** (G. K.), **Marvine** (A. R.), and **Howell** (E. E.). Southern and Southwestern Utah. Scale, 1 inch to 8 miles, or 1:506,880.

Accompanying "Geological atlas projected to illustrate United States geographical surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." New York, 1876.

748.

76—**Gilbert** (G. K.) and **Howell** (E. E.). Restored outline of Lake Bonneville. Scale, 1 inch to 17 miles.

Accompanying "Geological atlas projected to illustrate United States geographical surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." New York, 1876.

Not exactly a geological map, but a restoration of a great fresh-water lake (Lake Bonneville) as it existed during the quaternary period. Great Salt Lake, Utah Lake, and Sevier Lake are remains of that great lake, equal in extent to Lake Huron.

749.

1876—**Gilbert** (G. K.), **Marvine** (A. R.), and **Howell** (E. E.). Centr
Western Utah. Scale, 1 inch to 8 miles, or 1 : 506,880.
Accompanying "Geological atlas projected to illustrate United Sta
graphical surveys west of the 100th meridian of longitude, under t
mand of First Lieut. Geo. M. Wheeler." New York, 1876.

750.

1876—**King** (Clarence). Geological series. Map III. Utah
Scale, 4 miles to 1 inch.
Accompanying "Geological exploration of the fortieth parallel."
ical and topographical atlas, folio. (New York) 1876.
Two sheets.

751.

1876—**King** (Clarence). Geological series. Map IV. Nevada p
Scale, 4 miles to 1 inch.
Accompanying "Geological exploration of the fortieth parallel."
ical and topographical atlas, folio. (New York) 1876.
Two sheets.

752.

1876—**King** (Clarence). Geological series. Map V. Nevada
Scale, 4 miles to 1 inch.
Accompanying "Geological exploration of the fortieth parallel."
ical and topographical atlas, folio. (New York) 1876.
Two sheets.
The geological maps of the great folio atlas accompanying Clarenc
"Exploration of the fortieth parallel," five in numbers in ten sheets
10 geological maps—extending from Cheyenne to Pyramid Lake, are
ble contribution to the geology of a part of the Rocky Mountains a
Basin in the vicinity of the fortieth parallel. Mr. King had two otl
ogists associated with him, Messrs. S. F. Emmons and Arnold Hagu
to be regretted that the Spanish word *Cordilleras* has been used mo
criminately and inappropriately. Spanish geographers will be sur
learn that mountain ranges which have been placed by them as Sier
their discovery, are Cordillieras. It is not only a misapplication of
Cordillera, but an injustice toward the first scientific explorer of thi
General John C. Fremont, who gave the very appropriate name of
Basin" to the whole region between the Sierra Nevada and the
Mountains.

753.

1876—**Peale** (A. C.). Map of area B, showing the geology of
River Valley and the Book Cliffs.
Accompanying "Geological report on the Grand River district (Co
In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1876
annual report. Plate XI, p. 176. Washington, 1878.
Black etching.

754.

6—**Peale** (A. C.). Geological map of area A (lying between the San Miguel and Dolores Rivers).

Accompanying "Geological report on the Grand River district (Colorado)." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1876. Tenth annual report. Plate VIII, p. 165. Washington, 1878.

Black etching.

755.

76—**White** (C. A.). Geological map of a part of Northwest Colorado.

Accompanying "Report on the geology of a portion of Northwestern Colorado." In U. S. Geol. and Geogr. Surv. Territories. Explorations of 1876. Tenth annual report. Plate II, p. 60. Washington, 1878.

Black etching.

756.

177—**Gilbert** (G. K.). Map of the Henry Mountains. (Colored geologically) from a model in relief.

Accompanying "Report on the geology of the Henry Mountains." 4°. Southern Utah. Plate V. Washington, 1877.

757.

177—**Hayden** (F. V.). Northwestern Colorado and part of Utah. Scale, 4 miles to 1 inch, or 1:253,440.

Accompanying "Geological and geographical atlas of Colorado and portions of adjacent territory." Folio. Sheet XI. New York, 1877.

Published 1878. A. R. Marvine, A. C. Peale, F. M. Endlich, and C. A. White, geological assistants. Surveyed 1874–'76.

758.

177—**Hayden** (F. V.). Northern Central Colorado. Scale, 4 miles to 1 inch, or 1:253,440.

Accompanying "Geological and geographical atlas of Colorado and portions of adjacent territory." Folio. Sheet XII. New York, 1877.

Published 1878. A. R. Marvine, A. C. Peale, and W. H. Holmes, geological assistants. Surveyed in 1873–'74, and '75.

759.

177—**Hayden** (F. V.). Central Colorado. Scale, 4 miles to 1 inch, or 1:253,440.

Accompanying "Geological and geographical atlas of Colorado and portions of adjacent territory." Folio. Sheet XIII. New York, 1877.

Published 1878. F. M. Endlich, A. C. Peale, and W. H. Holmes, geological assistants. Surveyed in 1873–'74, and '75.

760.

177—**Hayden** (F. V.). Western Colorado and part of Utah. Scale, 4 miles to 1 inch, or 1:253,440.

Accompanying "Geological and geographical atlas of Colorado and portions of adjacent territory." Folio. Sheet XIV. New York, 1877.

Published 1878. A. C. Peale and W. H. Holmes, geological assistants. Surveyed in 1874–'75, and '76.

761.

1877—**Hayden** (F. V.). Southwestern Colorado and parts Mexico, Arizona, and Utah. Scale, 4 miles to 1 inch, or 1
Accompanying "Geological and geographical atlas of Colorado an of adjacent territory." Folio. Sheet XV. New York, 1877.
Published 1878. W. H. Holmes and F. M. Endlich, geological Surveyed in 1874–'75.

762.

1877—**Hayden** (F. V.). General geological map of Colorado. miles to 1 inch.
Accompanying "Geological and geographical atlas of Colorado an of adjacent territory." Folio. Sheet IV. New York, 1877.
Published in 1878. This map has been republished from the atla for 1876, and also for separate distribution.

763.

1877—**Hayden** (F. V.). Southern Central Colorado and part Mexico. Scale, 4 miles to 1 inch, or 1:253,440.
Accompanying "Geological and geographical atlas of Colorado an of adjacent territory." folio. Sheet XVI. New York, 1877.
Published 1878. F. M. Endlich, geological assistant. Surveyed i

764.

1878—**King** (Clarence). Analytical geological map of the an ploration of the fortieth parallel. I. Archæan and gra posures. Scale, 30 statute miles to 1 inch.
Accompanying "Geological exploration of the fortieth parallel." I. Systematic geology, p. 126. Washington, 1878.

765.

1878—**King** (Clarence). Analytical geological map of the an exploration of the fortieth parallel. II. Archæan, grai paleozoic exposures. Scale, 30 statute miles to 1 inch.
Accompanying "Geological exploration of the fortieth parallel." I. Systematic geology. p. 248. Washington, 1878.

766.

1878—**King** (Clarence). Analytical geological map of the are exploration of the fortieth parallel. III. Pre-mesozoic a zoic exposure. Scale, 30 statute miles to 1 inch.
Accompanying "Geological exploration of the fortieth parallel." I. Systematic geology, p. 356. Washington, 1878.

767.

1878—**King** (Clarence). Analytical geological map of the are exploration of the fortieth parallel. IV. Tertiary e Scale, 30 statute miles to 1 inch.
Accompanying "Geological exploration of the fortieth parallel." I. Systematic geology, p. 458. Washington, 1878.

768.

78—**King** (Clarence). Analytical geological map. VIII, IX, XI, and XII. Exposures of successive orographic disturbances.

Accompanying "Geological exploration of the fortieth parallel." 4°. Vol. I. Systematic geology, p. 760. Washington, 1879.

A set of five maps corresponding to atlas maps I, II, III, IV, V; giving geological axes, strike, dip, and angle of the strata.

769.

78—**King** (Clarence). Analytical geological map of the area of the exploration of the fortieth parallel. V. Glaciers of the ice age. Scale, 30 statute miles to an inch.

Accompanying "Geological exploration of the fortieth parallel." 4°. Vol. I. Systematic geology, p. 486. Washington, 1878.

This map is not geological, but merely a physical map giving a more or less exact topographical and physical map of the country during quaternary time.

770.

78—**King** (Clarence). Analytical geological map of the area of the exploration of the fortieth parallel. VI. Lakes of the glacial period.

Accompanying "Geological exploration of the fortieth parallel." 4°. Vol. I. Systematic geology, p. 529. Washington, 1878.

A physical map, only.

771.

78—**King** (Clarence). Analytical geological map of the area of the exploration of the fortieth parallel. VII. Tertiary volcanic rocks. Scale, 30 statute miles to 1 inch.

Accompanying "Geological exploration of the fortieth parallel." 4°. Vol. I. Systematic geology, p. 677. Washington, 1878.

772.

78—**Mudge** (B. F.). Map showing the superficial strata of Kansas.

Accompanying "Geology of Kansas." Topeka, 1878.

773.

'8—**Dutton** (C. E.). Geological map of the district of the high plateaus of Utah. Scale, 1 inch to 4 miles.

Accompanying "Report on the geology of the high plateaus of Utah, with atlas." 4°. Atlas, folio, sheet II. New York, 1879.

The atlas is dated 1879, the report 1880, and the distribution of both took place in 1881.

774.

1—**Becker** (G. F.). Geological map of Virginia, Nevada, and immediate vicinity. Scale, 1 inch = 1,500 feet.

Accompanying "A summary of the geology of the Comstock lode and the Washoe district." Second annual report of the United States geological survey. Report of the Secretary of the Interior for 1881. Vol. III, Plate, XLVI, p. 293. Washington, 1881.

775.

1881—**Dutton** (C. E.). Sketch map showing the distribution of t and eruptive rocks in the western part of the plateau p Scale, 16 miles to 1 inch, or 1: 1,000,000 nearly.

Accompanying "The physical geology of the Grand Cañon distr ond annual report of the United States geological survey. Report retary of the Interior for 1881. Vol. III. In pocket in back of volu ington, 1881.

776.

1881—**Emmons** (S. F.). Geological map of Leadville and vicin County, Colorado. Scale ½ mile to 1 inch, or 1:2,640.

Accompanying "Abstract of report on geology and mining indust ville, Lake county, Colorado." Second annual report of the Uni geological survey. Report of the Secretary of the Interior for 188 Plate XLIV, p. 240. Washington, 1881.

Carefully made geological map of a difficult and complicate Printed also separately.

777.

1881—**Hague** (Arnold). Geological map of Ruby Hill, Eureka district, Nevada.

Accompanying "Report of Mr. Arnold Hague. Division of the Pac ond annual report of the United States geological survey. Report retary of the Interior for 1881. Vol. III, Pl. IX, p. 22. Washingto

778.

1881—**Scudder** (S. H.). The tertiary lake basin at Florissant, C Scale, 1 mile to 1 inch.

Accompanying "The tertiary lake basin, at Florissant, Colorado South and Hayden Parks." In Bulletin of the U. S. Geol. and Ge Territories. Vol. VI, No. 2, p, 300. Washington, 1881.

Black etching.

## VII.—SOUTHWESTERN STATES AND TERRITORIES, COMPRISING ARKANSAS, LOUISIANA, INDIAN TERRITORY, NEW MEXICO, TEXAS, AND ARIZONA.

779.

19—**Roemer** (Ferdinand). Topographish-geognostische karte von Texas.

Accompanying "Texas." Bonn, 1849.

A very important geological map, the first of Texas.

780.

3—**Antisell** (Thomas). Geological plan and section from the Rio Grande to the Pimas villages, explored in 1856 by Lieut. John G. Parke. Scale, 1 : 1,200,000, nearly.

Accompanying "Reports of explorations and surveys for a Railroad route from the Mississippi River to the Pacific Ocean." 4to. Vol. VII, p. 206. Washington, 1857.

781.

3—**Blake** (W. P.). Geological map of the route explored by Lieut. A. W. Whipple, near the parallel of the 35° north latitude, from the Mississippi River to the Pacific Ocean. Prepared from the notes and collections of the geologist of the expedition, Mr. Jules Marcou.

Accompanying "Report of explorations and surveys for a Railroad route from the Mississippi River to the Pacific Ocean." 4to. Vol. III, p. 176, of Geological Report. Washington, 1856.

782.

57—**Blake** (W. P.). Geological map of the route explored by Capt. John Pope, near the 32d parallel of north latidude, from the Red River to the Rio Grande. Scale of 1 : 3,000,000.

Accompanying "Reports of explorations and surveys for a Railroad route from the Mississippi River to the Pacific Ocean." 4to. Vol. II, p. 40, of Geological Report. Washington, 1855.

The date of the publication of this volume is very confused. At the title page the date is 1855; on the geological map it is marked 1854; the report on the geology is dated 1856; and, finally, an explanatory note to geological report by John Pope is dated 1857. This last date is the true one.

783.

1857—**Marcou** (Jules). Geological map of New Mexico, from a survey made during the months of September, October, November and December, 1853. Scale, 1:900,000.

Accompanying "Geology of North America; with two reports on the prairies of Arkansas and Texas, the Rocky Mountains of New Mexico, and the Sierra Nevada of California." Originally made for the United States Government. 4to. Plate VIII. Zurich, 1858.

This map is the first geological map of New Mexico, and the first detailed geological map of any part of the country west of the 100th meridian.

784.

1858—**Newberry** (J. S.). Geological maps No. 1 and No. 2. Rio Colorado of the West (Arizona). Scale, 12 miles to an inch, or 1:760,320.

Accompanying "Geological report of the Colorado exploring expedition," Lieut. J. C. Ives in command. 4to. Washington, 1861.

Two sheets.

785.

1870—**Hopkins** (F. V.). Preliminary geological map of Louisiana.

Accompanying "First annual Report of the Louisiana geological survey, 1869. Louisiana State University, Baton Rouge." New Orleans, 1870.

The same map, without changes or alterations, accompanies the Second annual Report of the Louisiana geol. surv., New Orleans, 1871.

786.

1871—**Hopkins** (F. V.). Preliminary geological map of Louisiana.

Accompanying Second annual Report of the Louisiana geological survey. New Orleans, 1871.

See Hopkins (F. V.). 1870—No. 785.

787.

1871—**Hilgard** (E. W.). Geological map of the Mississippi embayment.

Accompanying "On the geological history of the Gulf of Mexico." Amer. Journ. Silliman. 3d series, Vol. II. New Haven, 1871.

Black etching.

788.

1871—**Hilgard** (E. W.). Geological map of the Mississippi embayment.

Accompanying "On the geology of lower Louisiana, and the salt deposit on Petite Anse Island." In Smithsonian Contributions to knowledge. p. 28. Washington, 1872.

Black etching.

789.

1872—**Loew** (Oscar) and **Roessler** (A. R.). Erforschung von Nordwest-Texas. Scale, 1:2,500,000.

Accompanying "Erforschung des Nordwest-theiles von Texas im Jahr 1872." Nach den Aufzeichnungen von Dr. O. Loew und A. Roessler zusammengestellt von Abb. S. Gatschet, in New York. Petermann's geographische Mittheilungen 4°. Vol. XIX, Plate XXIII. 1873. Gotha, 1873.

790.

4—**Roessler** (A. R.). A. S. Roessler's latest map of the State of Texas exhibiting mineral and agricultural districts, &c. Scale, 20 miles to an inch. New York, 1874.

791.

5—**Gilbert** (G. K.). Geological map of the Nutria fold and Zuñi range. Scale, 8 miles to 1 inch.

Accompanying "Geology of portions of New Mexico and Arizona;" in Report upon geographical and geological surveys west of the 100th meridian, in charge of first Lieut. Geo. M. Wheeler. Vol. III, geology. 4°. p. 561. Washington, 1875.

Black etching.

792.

5—**Roessler** (A. R.). Map of Llano County (Texas) showing geology, mineral localities, topography, &c. Scale, 4,000 varas to an inch. New York, 1875.

793.

—**Gilbert** (G. K.), **Marvine** (A. R.), and **Howell** (E. E.). Parts of Northern and Northwestern Arizona and Southern Utah. Scale, 1 inch to 8 miles, or 1:506,880.

Accompanying "Geological atlas projected to illustrate geographical explorations and surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." Sheet number 67. New York, 1876.

794.

7—**Marcou** (Jules), **Gilbert** (G. K.), and **Marvine** (A. R.). Parts of Central and Western Arizona. Scale, 1 inch to 8 miles, or 1:506,880.

Accompanying "Geological atlas projected to illustrate geographical explorations and surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." Sheet number 75. New York, 1877.

795.

7—**Gilbert** (G. K.), **Marvine** (A. R.), and **Howell** (E. E.). Part of Eastern Arizona and Western New Mexico. Scale, 1 inch to 8 miles, 1:506,880.

Accompanying "Geological atlas projected to illustrate geographical explorations and surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." Sheet number 76. New York, 1877.

Although my notes of 1853–1854 of the exploration of Lieut. A. W. Whipple have been made use of to a certain extent for the geographical distribution of the basalt, triassic, and carboniferous rocks, I requested Lieutenant Wheeler to withdraw my name from the list of geological assistants, on the ground of difference of opinion in regard to the geological age of several groups of rocks.—J. MARCOU.

796.

1877—**Gilbert** (G. K.), **Howell** (E. E.), and **Loew** (Oscar). Parts of Eastern and Southeastern Arizona, Western and Southwestern New Mexico. Scale, 1 inch to 8 miles, or 1:506,880.

Accompanying "Geological atlas projected to illustrate geographical explorations and surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." Sheet number 83. New York, 1877.

The Wheeler Geological Atlas, containing eleven sheets, published between 1875 and 1881, inclusive, is a very important contribution to our knowledge of the geology of the western regions.

797.

1877—**Stevenson** (J. J.). Part of North Central New Mexico. Scale, 1 inch to 4 miles, or 1:253,440.

Accompanying "Geological atlas projected to illustrate geographical explorations and surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." (New York.) (1877.)

See the same map by **Stevenson** (J. J.), 1881—No. 800.

798.

1881—**Gilbert** (G. K.), **Marvine** (A. R.), and **Howell** (E. E.). Parts of Colorado and New Mexico. Scale, 1 inch to 4 miles, or 1:253,440.

Accompanying "Geological atlas projected to illustrate geographical explorations and surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." New York, 1876.

Parts of sheets number 69, 77, and 78 of the geographical atlas, but in one sheet only of geological atlas.

799.

1881—**Stevenson** (J. J.). Parts of Southern Colorado and Northern New Mexico. Scale 1 inch to 4 miles, or 1:253,440.

Accompanying "Geological atlas projected to illustrate geographical explorations and surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." Sheet number 70 A. New York, 1881.

A first and very limited issue of this sheet was issued in May, 1877.

800.

1881—**Stevenson** (J. J.). Part of North Central New Mexico. Scale 1 inch to 4 miles, or 1:253,440.

Accompanying "Geological atlas projected to illustrate geographical explorations and surveys west of the 100th meridian of longitude, under the command of First Lieut. Geo. M. Wheeler." Sheet number 70 C. New York, 1881.

It is a second edition; the first being issued in May, 1877, but not distributed.

801.

1—**Stevenson** (J. J.). Part of Colorado and New Mexico. Scale, 1 inch to 4 miles, or 1:253,440.

Accompanying "Geological atlas projected to illustrate geographical explorations and surveys west of the 100th meridian longitude, under the command of First Lieut. Geo. M. Wheeler." New York, 1881.

Parts of sheets numbers 69 B, 69 D, 77 B, and 78 A, in one single sheet.

Prof. **Cope** and Dr. Oscar **Loe** assisted in part for the fragment of map No. 69 D.

N. B.—The three last maps by Stevenson (J. J.), Nos. 779, 800, and 801, were placed in pocket in back of Vol. III.—Supplement—Geology.—In Report upon Unite States geographical surveys west of the 100th meridian, in charged of Captain Geo. M. Wheeler. 4°. Washington, 1881.

## XVIII.—MEXICO.

802.

**1832—Burkhart** (Joseph). Geognostische Skizze des Weges von Tlalpujahua nach Huetamo dem Jorullo und Valladolid. Maasstab von 20 leguas 26.63 auf einen Grad.

Accompanying "Geognostiche Bemerkungen, gesammelt auf einer Reise von Tlalpujahua nach Huetamo, dem Jorullo, Patzcuaro, und Valladolid, im State von Michoacan." Karsten Archiv für Mineralogie, &c. Vol. V, Plate III. Berlin, 1832.

803.

**1836—Burkhart** (Joseph). Karte des Gebirges von Zacatecas.

Accompanying "Aufenthalt und Reisen in Mexico in den Jahren 1825 bis 1834." Stuttgart, 1836.

Not seen.

804.

**1838—Galeotti** (H. G.) Carte géognostique des environs de Zimapan au Méxique.

Accompanying "Notice géologique sur les environs de San José del Oro." Bulletin de l'Académie royale de Belgique, Vol. V, p. 737. Bruxelles, 1838.

805.

**1864—Egloffstein** (Baron F. W.) and **Gerolt** (Baron Frederich von). Geological map and profiles of some of the principal mining districts of Mexico. Scale of 12 miles to the inch, or 1 : 760,320.

Accompanying "Contributions to the geology and the physical geography of Mexico." New York, 1864.

Egloffstein is only the editor. The true author of the geological map, profiles, and descriptions is Baron Frederick von Gerolt, formerly Prussian minister at Mexico and afterwards at Washington.

806.

**1865—Dollfus** (Auguste) and **Montserrat** (Eugène de). Croquis géologique et topographique des environs de Toluca. Scale, 1 : 300,000.

Accompanying "Archives de la commission scientifique du Mexique." Tome III, p. 28. Paris, 1867.

807.

**1867—Dollfus** (Auguste), **Montserrat** (Eugène de), et **Pavie** (Paul). Carte géologique du district minier de Zomelahuacan. Scale, 1 : 75,000.

Accompanying "Archives de la commission scientifique du Mexique." Tome II, p. 338. Paris, 1867.

808.

71—**Barroso** (Agustin). Carta geologica del istmo de Tehuantepec, formada por la comision Mexicana que exploro el Istmo el ano, 1871. Scale, 1 : 500,000.

Accompanying "Memoria sobre la geologia del istmo de Tehuantepec." Anales del ministerio de Fomento de la republica Mexicana." Tomo III, p. 330. Mexico, 1880.

Date of exploration, 1871. Date of report, April, 1874, and date of publication, 1880.

809.

71—**Castillo** (Antonio del). Mapa topografico y geognostico de las immediaciones de las minas de azogue del Tequezquite en el departmento de Zacatecas. Scale, 3,000 varas mexicanas.

Accompanying "Memoria sobre las Minas de azogue de America." La Naturaleza, p. 48. 4°. Mexico, 1871.

Black, with mineralogical indications.

810.

71—**Spear** (J. C.). Geological map of the isthmus of Tehuantepec.

Accompanying "Reports of exploration and surveys, to ascertain the practicability of a ship canal between the Atlantic and Pacific Oceans," by Robert W. Shufeldt, Captain, U. S. N. 4°. Washington, 1872.

More exactly, a mineralogical and lithological map.

811.

73—**Barcena** (Mariano). Croquis geologico de una parte del estado de Queretaro.

Accompanying "Memoria presentada al Senor don Blas Balcarcel, director de la escuela especial de Ingenieros." Ministerio de justicia e instruccion publica de los Etados-Unidos Mexicanos. P. 9. 4°. Mexico, 1873.

812.

5—**Iglesias** (Miguel), **Barcena** (Mariano), et **Matute** (J. L.). Plano geologico del volcan del Ceboruco. Scale, 1 : 75,000.

Accompanying "Memoria de la comision exploradora del volcan del Ceboruco," near Tepic Jalisco. Anales del ministerio de Fomento de la republica Mexicana. Tomo I, p. 115, febrero de 1877. Mexico, 1877.

813.

6—**Barcena** (Mariano). Carta geologica de una parte del estado de Aguas Calientes.

Accompanying "Noticia geologica del Estado de Aguas calientes." El Propagador industrial. Tomo I, p. 348. 4°. Mexico, 1876.

814.

7—**Barcena** (Mariano). Formacion geologica del camino de Pachuca a Jacala y del distrito de este nombre, en el estado de Hidalgo.

Accompanying "Noticia cientifica de una parte del estado de Hidalgo." Anales del Ministerio de Fomento de la republica Mexicana. Tomo I. Marzo de 1877, p. 340. Mexico, 1877.

## XIX.—WEST INDIES OR ANTILLES, COMPRISING ALL THE ISLANDS BETWEEN THE BAHAMAS AND TRINIDAD.

815.

**1819—Nugent** (Nicholas). Map of the island of Antigua, in the West Indies.

Accompanying "A sketch of the geology of the island of Antigua." Transactions of the Geological Society. 4°. Vol. V, Plate XXXII. London, 1821.

816.

**1821—Maycock** (J. D.). Geological map of Barbadoes.

Accompanying "Geological description of Barbadoes, with a map of the island." The quarterly journal of science of the Royal Institution of Great Britain. Volume XI, Pl. I. London, 1821.

817.

**1825—De la Beche** (H. T.). Geological map of part of Jamaica.

Accompanying "Remarks on the geology of Jamaica." Transactions of the Geological Society, 2d series, 4° Vol. II, Part II, Plate XVIII. London, 1827.

818.

**1843—Taylor** (R. C.). Rough sketch or reconnaissance of the copper region and of the geology of the Savanna region of Gibara in the island of Cuba. Scale, 1 mile to 1 inch.

Accompanying "Memoir on the character and prospects of the copper region of Gibara, and a sketch of the geology of the northeast part of the island of Cuba." Trans. Amer. Phil. Soc. New Series, 4°, Vol. IX, Article VII, Plate XXXIII. Philadelphia, 1846.

Black with geological indications.

819.

**1860—Wall** (G. P.) and **Sawkins** (J. G.). Geological map of Trinidad. Scale, 1 inch to 4 miles.

Accompanying "Report on the geology of Trinidad." London, 1860.

820.

**1864—Duncan** (P. M.) and **Wall** (G. P.). Geological sketch-map of the district of upper Clarendon, Jamaica.

Accompanying "A notice of the geology of Jamaica, especially with reference to the district of Clarendon." Journ. Geol. Soc. London, Vol. XXI, p. 3. London, 1865.

Black etching.

821.

865—**Sawkins** (J. G.) and **Brown** (C. Barrington). Geological map of Jamaica. Scale, one mile to ¼ of an inch, or 1 : 253,410.

Accompanying "Reports on the geology of Jamaica." London, 1869.

822.

66—**Julien** (A. A.). Key of Sombrero, W. I. Scale, 800 feet to the inch.

Accompanying "On the geology of the Key of Sombrero, West India." Annals of Lyceum of Natural History of New York, Vol. VIII, Plate IV. New York, 1867.

Black etching.

823.

71—**Cleve** (P. T.). Map of Salt Island, Cooper Island, Ginger Island, and Round Rock.

Accompanying "On the geology of the northeastern West India Islands." Kongl. Svenska Vetenskaps-Akademiens Handlingar, Bandet 9, No. 12, p. 13. 4°. Stockholm, 1871.

Black etching.

824.

71—**Cleve** (P. T.). No title (map of Puerto Rico).

Accompanying "On the geology of the northeastern West India Islands." Kongl. Svenska Vetenskaps-Akademiens Handlingar Bandet 9, No. 12, p. 15. 4°. Stockholm, 1871.

Black etching.

825.

71—**Cleve** (P. T.). No title (map of Saba Island).

Accompanying "On the geology of the northeastern West India Islands." Kongl. Svenska Vetenskaps-Akademiens Handlingar, Bandet 9, No. 12, p. 19. 4°. Stockholm, 1871.

Black etching.

826.

71—**Cleve** (P. T.). Map of St. Martin.

Accompanying "On the geology of the northeastern West India Islands." Kongl. Svenska Vetenskaps-Akademiens Handlingar, Bandet 9, No. 12, p. 23. 4°. Stockholm, 1871.

Black etching.

827.

71—**Cleve** (P. T.). Geological map over the northeastern West India Islands. Scale, $\frac{1}{1,751,000}$.

Accompanying "On the geology of the northeastern West India Islands." Kongl. Svenska Vetenskaps-Akademiens Handlingar, Bandet 9, No. 12, Tafl. I. 4°. Stockholm, 1871.

Black etching.

828.

**1871—Cleve** (P. T.). Geological map over a part of the Virgin Islands, W. I.

Accompanying "On the geology of the northeastern West India Islands." Kongl. Svenska Vetenskaps-Akademiens Handlingar, Bandet 9, No. 12, Tafl. II. 4°. Stockholm, 1871.

Black etching.

829.

**1871—Cleve** (P. T.). Geological map over St. Croix. Scale, $\frac{1}{\text{illegible}}$.

Accompanying "On the geology of the northeastern West India Islands." Kongl. Svenska Vetenskaps-Akademiens Handlingar, Bandet 9, No. 12, Tafl. II. 4°. Stockholm, 1871.

Black etching.

830.

**1871—Cleve** (P. T.). Geological map over St. Bartholomew.

Accompanying "On the geology of the northeastern West India Islands." Kongl. Svenska Vetenskaps-Akademiens Handlingar, Bandet 9, No. 12, Tafl. II. 4°. Stockholm, 1871.

Black etching.

831.

**1872—Gabb** (W. M.). Geological map of the Republic of Santo Domingo. Scale, 12 miles to the inch.

Accompanying "On the topography and geology of Santo Domingo." Trans. Amer. Phil. Soc., New Series, Vol. XV, Article IV, p. 260. 4°. Philadelphia, 1881.

832.

**1877—Guppy** (R. J. L.). Sketch map of the northwestern part of Trinidad.

Accompanying "On the physical geography and fossils of the older rocks of Trinidad." Proceedings of the Scientific Association of Trinidad, Vol. II, p. 115. Port of Spain, 1877.

Black etching.

833.

**1880—Salterain y Legarra** (Pedro). Mapa geológico y topográfico en bosquejo de las jurisdicciones de la Habana y Guanabacoa (Isla de Cuba). Scale, 1 : 200,000.

Accompanying "Apuntes fisico-geológicos de la Habana y Guanabacoa." Boletin de la comision del mapa geológico de España, tomo VII. Lamina D. Madrid, 1880.

An important and well executed map. Published also separately.

## I.—CENTRAL AMERICA, COMPRISING BRITISH HONDURAS OR BELIZE, HONDURAS, GUATEMALA, SALVADOR, NICARAGUA, AND COSTA RICA.

834.

**65-1868—Dollfus** (Auguste) and **de Montserrat** (Eugène). Esquisse d'une carte géologique d'une partie des républiques de Guatemala et de Salvador (Amérique Centrale). Scale, 1 : 761,000.

Accompanying "Voyage géologique dans les républiques de Guatemala et de Salvador." Planche V. 4°. Paris, 1868.

Very important and well executed.

XIX.

1865.—Gerstaecker, Adolf F. Carte de l'Amérique méridionale indiquant les différentes espèces guanaques.

Accompanying "Voyage dans l'Amérique méridionale," tome III, 3me partie, zoologie, atlas. Planche I. Paris, 1868.

Base missing.

XX.

1866.—Petermann, Aug. Geologische Uebersichts-Karte von Süd-Amerika. Scale 1 : 35,000,000.

Accompanying "Die Geologie von Süd-Amerika." Petermann's geographische Mittheilungen, Ergänzungsheft No. 21, p. 87. Plate 11. 4°. Gotha, 1867.

XXI.

1873.—Marcou de Mercey, J. Carte géologique de l'Amérique du Sud.

Accompanying "Description géographique et statistique de la Confédération Argentine," 2me édition. Atlas. Planche XIX. folio. Paris, 1873.

A compilation of Pentland and Marcou geological maps of South America and The World.

838.

—**Degenhardt** (Carl). Plan-Umgegend von El Quarzo der Salzquellen und der Goldseifenwercke. Maasstab von 900 englischen Lachtern à 6 Fuss.

Accompanying "Ueber die Salzquellen des nördlichen Theiles der Provinz Antioquia und die Gebirgsformationen der Umgebung von Medellin im Freistaate von Neu-Grenada." Karsten: Archiv für Mineralogie, etc. Vol. XII. Taf. I. Berlin, 1839.

839.

—**Degenhardt** (Carl). Carte géologique du district de la Baja, province de Pamplona, Colombie.

Accompanying "Monatsberichte über die Verhandlungen der Gesellschaft für Erdkunde zu Berlin." Berlin, 1842.

Not seen.

840.

—**Karsten** (Hermann). Geognostische Karte des nordöstlichen Venezuela.

Accompanying "Beitrag zur Kenntniss der Gesteine des nördlichen Venezuela." In the Zeitschrift der deutschen geologischen Gesellschaft. II. Band. Taf. XI. Berlin, 1850.

841.

—**Anonymous.** Isthmus of Panama; geological coloring.

Accompanying the upper left hand corner of "A new map of Central America, showing the different lines of Atlantic and Pacific communication." Published by J. Disturnel. New York, 1850.

A fancy geological map made for the gold seekers of California, 1849-'50.

842.

—**Taylor** (R. C.). A map of the Rio Palenque, R. Escribanos, R. Valencia, and R. del Rey, in the auriferous porphyry region of the Province of Veraguas and Isthmus of Panama. Scale of $\frac{8}{8}$ of an inch to a mile.

Accompanying "Substance of notes made during a geological reconnaissance in the auriferous porphyry region next the Caribbean Sea." Journ. Acad. Nat. Sciences of Philadelphia. 4°. 2d Series. Vol. II. Article IX, p. 184. Plate X. Philadelphia, 1850-'54

Black, with geological indications.

843.

1856—**Karsten** (Hermann). Karte der Verbreitung der geognostischen Formationen in Columbien.

Accompanying "Die geognostischen Verhältnisse Neu-Granada's." Verhandlungen der Versammlung deutscher Naturforscher. 4°. Wien, 1856.

844.

1856—**Karsten** (Hermann). Columbien zur Zeit der Kreideformation.

Accompanying "Die geognostischen Verhältnisse Neu-Granada's." Verhandlungen der Versammlung deutscher Naturforscher. 4°. Wien, 1856.

Black etching. This map is on the same sheet with the one previously cited.

845.

1860—**Wall** (G. P.). Maps and sections of the northern part of South America.

Accompanying "On the geology of a part of Venezuela and of Trinidad." Journ. Geol. Soc. London. Vol. XVI, p. 460. London, 1860.

Black etching.

## XXIII.—GUIANA AND BRAZIL.

846.

1—**Claussen** (P.). Carte géologiqûe d'une partie de la province de Minas Geraes au Brésil.

Accompanying "Notes géologiques sur la province de Minas Geraes au Brésil." Bull. Acad. royal de Bruxelles, tome VIII, No. 5. Bruxelles, 1841.

847.

—**Foetterle** (Francisco) and **Haidinger** (Guilherme). Golpe de vista geologico do Brezil e de algunas outras partes centraes de America do Sul. Scale 1: 15,000,000.

Accompanying "Die geologische Uebersichtskarte des mittleren Theiles von Süd-Amerika." Wien, April, 1854.

This map, in Portuguese language, and published with a memoir in German to explain it, was constructed for Prof. Dr. von Martins, of München, for his great work on Brazil.

848.

—**Hartt** (C. F.). Sketch map of vicinity of Monte Alegre and Ereré.

Accompanying "Contributions to the geology and physical geography of the Lower Amazonas," in Bulletin Buffalo's Soc. Nat. Sciences, p. 201. Buffalo, 1871.

Black, with geological indications.

849.

—**Brown** (C. Barrington). Geological map of British Guiana. Scale, one inch to 13:6 geographical miles.

Accompanying "Reports on the physical, descriptive, and economic geology of British Guiana," by C. B. Brown and J. G. Sawkins. London, 1875.

850.

—**Brown** (C. Barrington). Map of a portion of South America, showing the position and extent of the old river-deposit on the Amazon, east of Tabatinga.

Accompanying "On the ancient river-deposit of the Amazon." Jour. Geol. Soc. London, Vol. XXXV, p. 763. Plate XXXVIII. London, 1879.

Black etching.

## XXIV.—PARAGUAY, URUGUAY, REPUBLICA ARGENTINA, PATAGONIA, FALKLAND ISLANDS OR ISLAS MALVINAS, AND TIERRA DEL FUEGO.

851.

**1835—Orbigny** (Alcide d'). Carte géologique d'une partie de la République Argentine, comprenant les provinces de Corrientes et de Missions.

Accompanying "Voyage dans l'Amérique méridionale"; partie historique Atlas. Carte No. 3. Paris, 1835.

852.

**1838—Orbigny** (Alcide d'). Carte géologique d'une partie de la République Argentine, comprenant les provinces de Santa Fé, d'Entre-Rios, de Buenos-Aires, et la partie septentrionale de la Patagonie. Scale, 20 lieues au degré.

Accompanying "Voyage dans l'Amérique méridionale"; partie historique. Atlas. Carte No. 1. Paris, 1838.

853.

**1857—Bravard** (Auguste). Mapa geologico y topografico de los alrededores de Bahia Blanca. Buenos Ayres, 1857.

Unseen. Copied from "Compte rendu de la Société de Géographie de Paris," No. 1, 1884, p. 32, Paris, where the name of the author is given as Ravard.

854.

**1869—Martin de Moussy** (V.). Carte physique de la Confédération Argentine.

Accompanying "Description géographique et statistique de la Confédération Argentine." Deuxième édition, atlas, planche XX. folio. Paris, 1873.

855.

**1875—Stelzner** (Alfr.). A geological map of a part of the Argentine Republic.

Accompanying "Boletin de la Academia nacional de ciencias exactas existentes en la universidad," Vol. I. Buenos Ayres, 1875.

Unseen; published by Dr. Burmeister.

856.

**76—Burmeister** (Hermann). Carte géognostique d'une partie de la République Argentine entre les 65°–73° de longitude et 25°–34° de latitude.

Accompanying "Tableau géognostique de la République Argentine. Description physique de la République Argentine." Tome II, livre IV, p. 151. Paris, 1876.

857.

**76—Schickendantz** (Federico). No title. (A small sketch map of a part of the province of Catamarca.)

Accompanying "The natural sulphates of the province of Catamarca." In, The Argentine Republic, by Richard Napp, p. 215. Buenos Aires, 1876.

Black, with geological inscriptions.

858.

**0—Lallemant** (G. A.). Los lavaderos y criaderos auriféros.

Accompanying "Notas sobre los lavaderos y criaderos auriféros de los Cerritos Blancos en la sierra de San Luis." Anales de la Sociedad científica Argentina. Tomo IX, Entrega V, p. 208. Buenos Aires, 1880.

Black etching; the text says it is colored, los lavaderos = color de carmin; los cumulos de traquita = color amarillo.

859.

**1827—Rivero** (M. de). View and topographical plan of the new t of the hill Pasco, taken from the lake of Quinlacocha.

Accompanying "A sketch of the rich mine of Pasco." Amer. Journ. mann. Vol. XV. New Haven, 1829.

This map is colored lithologically in five colors. Translated from Jo of Natural Science and National and Foreign Industry of M. de Rivero. I, No. 2. Lima, 1828.

860.

**1840—Domeyko** (Ignace). Esquisse d'une carte géologique de la v d'Elqui.

Accompanying "Sur un terrain stratifié situé dans le haut des Cordill et sur les silons métallifères qui l'accompagnent." Annales des mines, 3e Tome XVIII, Pl. II, p. 59. Paris, 1840.

Black etching.

861.

**1842—Orbigny** (Alcide d'). Carte géologique de la République de Bol

Accompanying "Voyage dans l'Amérique méridionale." Tome III, 3me p Géologie. Atlas. Carte No. 4. Paris, 1842.

The most important geological map on South America, giving data c geological structure of the Andes, for the first time in geology.

862.

**1846—Domeyko** (Ignace). Carte géologique et minéralogique du C

Accompanying "Recherches sur la constitution géologique du Chili." nales des mines, 4e série Vol. IX, Planche IV, p. 365. Paris, 1846.

Black etching. The first important and exact geological work on Ch

863.

**1846—Domeyko** (Ignace). Carte géologique des environs de Coqui

Accompanying "Sur le terrain tertiaire et les lignes d'ancien nive l'Océan du sud, aux environs de Coquimbo (Chili)." Annales des mi série. Vol. XIV, p. 153, Pl. II. Paris, 1848.

Black etching.

864.

**1848—Domeyko** (Ignace). Carte géologique des environs de la Co cion.

Accompanying "Sur la composition géologique du Chili, à la latitu Concepcion, depuis la baie de Talcahuano jusqu' au sommet de la cord de Pichachen, comprenant la description du volcan d'Antuco." Annal mines, 4e série. Vol. XIV, pp. 163 et 186. Pl. III. Paris, 1848.

Black etching.

865.

**Forbes** (David). Geological sketch map of part of Bolivia and Peru.

Accompanying "Report on the geology of South America, by David Forbes. Part I. Bolivia and Southern Peru, with notes on the fossils, by Huxley, Salter, and Jones." Journ. Geol. Soc. London. Vol. XVII. London, 1861.

An important map, on a very small scale, which corrects some parts of d'Orbigny's map; it is also separately printed.

866.

**Simonin** (Louis). Carte des terrains métallifères du Chili, d'après Gay et Domeyko.

Accompanying "La vie souterraine, ou les mines et les mineurs." Carte XII, p. 424. Paris, 1867.

867.

**Concha** i Toro (Enrique). Plano que indiqua la situacion del Terreno Terciario inferior i cretaceo superior entre los Puertos de Tomé i Leuvu.

Accompanying "Memoria sobre los formaciones cuaternarias, terciarias, i cretácea (superior) de Chile, relativas principalmente a la parte meridional de este pais." Anales de la Universidad de Chile, tomo XXXII, no. 5, p. 390. Santiago de Chile, 1869.

Black etching.

868.

**Pissis** (A.). Plano topographico y geologico de la Republica de Chile levantado por órden del gobierno, bajo la direccion de A. Pissis. Scale, 1 : 250,000. Paris, 1873.

In 13 sheets. No date nor place of publication, but 1873 may be considered as the exact date of issue, and Paris is the place where it was executed. The map is colored geologically, but a certain number of copies have been issued in black with limit of the rocks in dotted lines, and geological inscriptions with letters.

It is the most important geological map and work published as yet on South America, and is very creditable, both to its author, M. A. Pissis, and the Chilian Government.

869.

**Pissis** (A.). Carte géologique de la région des Andes entre 22° et 42° Sud. Scale, 1 : 5,000,000.

Accompanying "Mémoire sur la constitution géologique de la chaîne des Andes entre le 16e et le 53e degré de latitude sud." Annales des mines, vol. III, p. 404. Paris, 1873.

A valuable map, giving, on a smaller scale, the results contained in Pissis' large map in 13 sheets.

870.

**Pissis** (A.). Plano del grupo volcanico de los volcanes del Descabezado (Chile). Scale, 1 : 100,000.

Accompanying "Atlas de la geografía física de la República de Chile." Lamina 19. In folio. Paris, 1875.

Explanation of the atlas, in Geografía física de la República de Chile, p. 341.

# SUPPLEMENT.

**The number between brackets shows the correct position of the map in the general catalogue.**

## II.—NORTH AMERICA IN GENERAL.

871 [30*a*].

**1843—Castelnau** (Francis de). Carte théorique de l'Amérique Sept^ale avant le soulèvement des Illinois. (Epoque silurienne.)

Accompanying "Essai sur le système Silurien de l'Amérique septentrionale." 4°. Pl. I. Paris, 1843.

In black. A very rough sketch map with geological inscriptions only.

872 [59*a*].

**1866—Daddow** (S. H.). Map of the Alleghany coal field.

Accompanying "Coal, iron, and oil; or the practical American miner," p. 318. Pottsville, Pa., 1866.

In black.

873 [59*b*].

**1866—Daddow** (S. H.). Map of the great coal field in Iowa and Missouri.

Accompanying "Coal, iron, and oil; or the practical American miner," p. 377. Pottsville, Pa., 1866.

In black.

874 [59*c*].

**1866—Daddow** (S. H.) and **Bannan** (Benjamin). Great central coal field. (Illinois, Indiana, and western Kentucky.)

Accompanying "Coal, iron, and oil; or the practical American miner," p. 362. Pottsville, Pa., 1866.

In black.

875 [80*a*].

**1880—Hayden** (F. V.). General geological map of the area explored and mapped by Dr. F. V. Hayden and the surveys under his charge, 1869 to 1880. Scale, 1:2,600,000 or 41.03 miles to 1 inch.

Accompanying "Twelfth annual report of the U. S. Geol. and Geogr. Surv. Territories, for the year 1878." Maps and panoramas in accompanying pocket, sheet XI. Washington, 1883.

This map was issued February, 1884, several months after the report and pocket. It embraces Nebraska, Dakota, Montana, Idaho, Wyoming, Utah, Colorado, and very small portions of New Mexico and Arizona.

876 [80*b*].

**(1881)—Chamberlin** (T. C.). Geological map of the United States, compiled from various official sources.

Accompanying "Wisconsin geological survey," Vol. I, Part I, Pl. III, p. 79. Madison, 1883.

Black etching. There is no name of author nor date on the map.

## V.—ACADIA.

877 [131*a*].

**1866—Daddow** (S. H.) and **Bannan** (Benjamin). Maps of the Arcadian Coal fields.

Accompanying "Coal, iron, and oil; or the practical American miner," p. 387. Pottsville, Pa., 1866.

In black. A reduced copy of the map of the New Brunswick, Nova Scotia, Cape Breton, and Newfoundland coal fields, by R. C. Taylor.

See **Taylor** (R. C.), 1848—No. 121.

## VII.—NEW ENGLAND.

878 [208*a*].

**1848—Thompson** (Zadock). Geological map of Vermont.

Accompanying "Geography and geology of Vermont," p. 44. 12°. Burlington, 1848.

Black etching.

879 [276*a*].

**1856—Lesley** (J. P.). No title. (Map intended to exhibit the north-eastern portion of the great eastern coal field of the United States.)

Accompanying "Manual of coal and its topography," 12°, p. 76, fig. 20. Philadelphia, 1856.

Black etching.

880 [276*b*].

**1856—Lesley** (J. P.). No title. (Map of the region of the Juniata.)

Accompanying "Manual of coal and its topography," 12°, p. 137, fig. 37. Philadelphia, 1856.

In black.

881 [285*a*].

**1866—Daddow** (S. H.) and **Bannan** (Benjamin). Map of the Broad Top coal field.

Accompanying "Coal, iron, and oil; or the practical American miner," p. 299. Pottsville, Pa., 1866.

In black.

882 [285*b*].

**1866—Daddow** (S. H.) and **Bannan** (Benjamin). Map of Cumberland coal field (Maryland).

Accompanying "Coal, iron, and oil; or the practical American miner," p. 332. Pottsville, Pa., 1866.

In black.

883 [307*a*].

**1876—Lesley** (J. P.) and **Frazer** (P., jr.). Geological maps of Adams County.

Accompanying "2d Geol. Surv. Pennsylvania." Adams, Franklin, Cumberland maps, atlas, D. 5. Harrisburg (1883).

884 [324*a*].

**1878—Lesley** (J. P.), **Prime** (F., jr.), **Clark** (E., jr.), and **Berlin** (A. P.). Geological and Topographical map of a part of Northampton County.

Accompanying "2d Geol. Surv. Pennsylvania." Lehigh, Northampton, and Berks, atlas to D. 3, Vol. I and Vol. II. Harrisburg, 1878.

In six sheets.

885 [343*a*].

**1880—Frazer** (P., jr.). Geological map of Chester County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." The geology of Chester County, C. 4. Harrisburg, 1883.

886 [343*b*].

**1880—Lesley** (J. P.). Geological map of Cumberland County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Adams, Franklin, Cumberland maps, atlas D. 5. Harrisburg (1883).

887 [349*a*].

**1881—Lewis** (H. C.) and **Wright** (G. F.). Map showing the course of the great terminal Moraine across Pennsylvania.

Accompanying "2d Geol. Surv. Pennsylvania." Report on the terminal Moraine in Pennsylvania and Western New York. Report of progress. Z. Harrisburg, 1884.

888 [351*a*].

**1881—Sanders** (R. H.). Geological map of Franklin County. Scale, 2 miles to 1 inch.

Accompanying "2d Geol. Surv. Pennsylvania." Adams, Franklin, Cumberland, atlas D. 5. Harrisburg (1883).

889 [528*a*].

**1879—King** (F. H.). Map of a portion of the Upper Flambeau val showing the position of Archæan exposures.

Accompanying "Wisconsin geological survey," Vol. IV, Part VI, Pl. I p. 585. Madison, 1882.

Black, with lithological inscriptions. There is no name of author on map.

890 [536*a*].

**1881—Chamberlin** (T. C.). General geological map of Wisconsin.

Accompanying "Wisconsin geological survey." Atlas, Vol. IV, folio, P Milwaukee, 1882.

891 [536*b*].

**1881—Chamberlin** (T. C.). General map of the Quaternary formati of Wisconsin.

Accompanying "Wisconsin geological survey." Atlas, Vol. IV, folio, Pl. Milwaukee, 1882.

892 [536*c*].

**1881—Chamberlin** (T. C.). General geological map of Wisconsin.

Accompanying "Wisconsin geological survey," Vol. I, Part I, Pl. II, p. Madison, 1883.

Black etching. There is no name of author on the map.

893 [536*d*].

**(1881)—Irving** (R. D.). Crystalline rocks of the Wisconsin valley (fr Pine river to Grandfather Bull falls; sketch map No. VI Scale, 1⅓ miles to 1 inch.

Accompanying "Wisconsin geological survey," Vol. IV, Part VII, Pl. X p. 702. Madison, 1882.

Black etching and lithological inscriptions. There is no date nor nam author on the map.

894 [536*e*].

**(1881)—Irving** (R. D.). Crystalline rocks of the Wisconsin valley (fi Junction river to Mosinee; sketch map No. IV). Scale, 1⅓ m to 1 inch.

Accompanying "Wisconsin geological survey," Vol. IV, Part VII, Pl. X p. 650. Madison, 1882.

Black, with lithological inscriptions. There is no date nor name of au on the map.

895 [536*f*].

31)—**Irving** (R. D.). Crystalline rocks of the Wisconsin valley. (Vicinity of Wausau; sketch map No. V.) Scale, 1⅛ miles to 1 inch.

Accompanying "Wisconsin geological survey," Vol. IV, Part VII, Pl. XVIII, p. 661. Madison, 1882.

Black, with lithological inscriptions. There is no date nor name of author on the map.

896 [536*g*].

1—**Irving** (R. D.). Crystalline rocks of the Wisconsin valley. (Upper Eau Claire River; sketch map No. VI.) Scale, 1⅛ miles to 1 inch.

Accompanying "Wisconsin geological survey," Vol. IV, Part VII, Pl. XIX, p. 686. Madison, 1882.

Black etching and lithological inscriptions. There is no date nor name of author on the map.

897 [536*h*].

31—**Irving** (R. D.). Crystalline rocks of the Wisconsin valley. (Rib River valley above Marathon; sketch map No. VII.) Scale, 1⅛ miles to 1 inch.

Accompanying "Wisconsin geological survey," Vol. IV, Part VII, Pl. XX, p. 692. Madison, 1882.

Black etching and lithological inscriptions. There is no date nor name of author on the map.

898 [536*i*].

1—**Irving** (R. D.). Map illustrating the general distribution of the crystalline rocks of the upper Wisconsin valley. Scale, 6 miles to 1 inch.

Accompanying "Wisconsin geological survey," Vol. IV, Part VII, No. 1, p. 625. Madison, 1882.

There is no date nor name of author on the map. By an oversight this map has been numbered No. 1, and is not contained in the list of illustrations, lithographic plates p. xxii.

899 [536*j*].

1—**Irving** (R. D.). Crystalline rocks of the Wisconsin valley. (Vicinity of Grand Rapids; sketch map No. I.) Scale, 1⅛ miles to 1 inch.

Accompanying "Wisconsin geological survey," Vol. IV, Part VII, Pl. XIV, p. 627. Madison, 1882.

There is no date nor name of author on the map. It is also numbered No. I, like the preceding map.

See **Irving** (R. D.), 1881—No. 898.

900 [536*k*].

1881—Irving (R. D.). Crystalline rocks of the Wisconsin v
(Vicinity of Stevens Point; sketch map No. II.)
Accompanying "Wisconsin geological survey," Vol. IV, Part VII, P
p. 639. Madison, 1882.
There is no date nor scale nor name of author on the map.

901 [536*l*].

1881—Irving (R. D.). Crystalline rocks of the Wisconsin v
(Yellow River; sketch map No. III.) Scale, 1½ miles to 1 i
Accompanying "Wisconsin geological survey," Vol. IV, Part VII, Pl
p. 645. Madison, 1882.
There is no date nor name of author on the map.

902 [582*a*].

**[illegible]—Daddow** (S. H.). Map of the Richmond and Piedmont coal fields. (Virginia.)

Accompanying "Coal, iron, and oil; or the practical American miner," p. 395. Pottsville, Pa., 1866.

In black.

903 [582*b*].

**[illegible]—Daddow** (S. H.). Dan River and Deep River coal fields. (Virginia and North Carolina.)

Accompanying "Coal, iron, and oil; or the practical American miner," p. 404. Pottsville, Pa., 1866.

In black.

904 [582*d*].

**[illegible]—Daddow** (S. H.) and **Bannan** (Benjamin). Map of the great Kanawha valley and the iron regions at the head of the New River. Scale, fifty miles to an inch.

Accompanying "Coal, iron, and oil; or the practical American miner," p. 346. Pottsville, Pa., 1866.

In black.

905 [582*e*].

**[illegible]—Daddow** (S. H.) and **Bannan** (Benjamin). Map of the New River coal fields. (Virginia.)

Accompanying "Coal, iron, and oil; or the practical American miner," p. 407. Pottsville, Pa., 1866.

In black.

906 [582*f*].

**[illegible]—Daddow** (S. H.) and **Bannan** (Benjamin). The Alleghany coal field in Alabama.

Accompanying "Coal, iron, and oil; or the practical American miner," p. p. 355. Pottsville, Pa., 1866.

In black.

907 [590*a*].

**[illegible]esley** (J. P.). Scott's mine at (*b*) on Middle Creek, Russell [illegible]ounty.

Accompanying "The geological structure of Tazewell, Russell, and Wise [illegible]unties in Virginia." Proc. Amer. Phil. Soc., Vol. XII, p. 500, Philadel[illegible]a, 1873.

[illegible]mall black sketch, with lithological indications.

908 [612*a*].

1881—**Crandall** (A. R.). Kentucky geological survey. Elliot County. Scale, 2 miles = 1 inch. (New York, 1881.)

No date nor place of publication on the map.

909 [612*b*].

1881—**Fales** (J. C.) and **Linney** (W. M.). Kentucky geological survey. Boyle and Mercer counties. Geology of Boyle County, by J. C. Fales. Geology of Mercer County, by W. M. Linney. Scale, 2 miles = 1 inch. (New York, 1881.)

No date nor place of publication on the map.

910 [613*a*].

1881—**Linney** (W. M.). Kentucky geological survey. Garrard County. Scale, 2 miles = 1 inch. (New York, 1881.)

No date nor place of publication on the map.

911 [613*b*].

1881—**Linney** (W. M.). Kentucky geological survey. Lincoln County. Scale, 2 miles = 1 inch. (New York, 1881.)

No date nor place of publication on the map.

912 [613*c*].

1881—**Linney** (W. M.). Kentucky geological survey. Spencer and Nelson Counties. Scale, 2 miles = 1 inch. (New York, 1881.)

No date nor place of publication on the map.

913 [613*d*].

1881—**Linney** (W. M.) and **Knott** (W. T.). Kentucky geological survey. Washington and Marion counties. Geology of Washington County, by W. M. Linney. Geology of Marion County, by W. T. Knott. Scale, 2 miles = 1 inch. (New York, 1881.)

No date nor place of publication on the map.

914 [613*e*].

1881—**Proctor** (J. R.). Map of Kentucky from the Eclectic geographies. Scale, natural size as 1 to 1,679,000; 26½ miles to the inch.

Accompanying "Kentucky geological survey." New series. Kentucky Bureau für Geologie und Einwanderung. Die materiellen Verhältnisse und Vortheile für Einwanderer im Staate Kentucky. Zweite Auflage. Frankfort, Ky., 1881.

Black etching and geological indications. This map was also published in the same work in English and in Scandinavian, neither of which have we been able to see.

915 [613*f*].

1881—**Proctor** (J. R.). Map of Kentucky from the Eclectic geographies. Scale, natural size as 1 to 1,679,000; 26½ miles to the inch.

There is no date nor place of publication on the map, but the copyright is dated 1882. The map is published separately, having some statistics printed on the back, by the Kentucky geological survey and bureau of immigration. With the exception of the geological coloring it is the same as map No. 914.

916 [636*a*].

1878—**Endlich** (F. M.). (Geological map of) Part of Central Wyoming. Scale, 4 miles to 1 inch, or 1 : 253,440.

Accompanying "Twelfth annual report of the U. S. Geol. and Geogr. Surv. Territories for the year 1878." Maps and panoramas in accompanying pocket, sheet 3. Washington, 1883.

917 [636*b*].

1878—**Hayden** (F. V.) and **Holmes** (W. H.). Preliminary geological map of the Yellowstone National Park. Scale, 2 miles to 1 inch, or 1 : 126,720.

Accompanying "Twelfth annual report of the U. S. Geol. and Geogr. Surv. Territories for the year 1878." Maps and panoramas in accompanying pocket, sheet 6. Washington, 1883.

918 [636*c*].

1878—**Holmes** (W. H.). No title. (Map showing displacements, Yellowstone valley.)

Accompanying "Report on the geology of the Yellowstone National Park." U. S. Geol. and Geogr. Surv. Territories; twelfth annual report for the year 1878. In two parts. Part II, Pl. III, p. 6. Washington, 1883.

Black etching and geological indications. The title is in the list of illustrations.

919 [636*d*].

1878—**Holmes** (W. H.). Sketch map of the geology of Junction valley (National Park).

Accompanying "Report on the geology of the Yellowstone National Park." U. S. Geol. and Geogr. Surv. Territories; twelfth annual report for the year 1878. In two parts. Part II, Pl. XXII, p. 42. Washington, 1883.

Black etching.

920 [636*e*].

1878—**Holmes** (W. H.). Distribution of Glacial boulders (National Park).

Accompanying "Report on the geology of the Yellowstone National Park." U. S. Geol. and Geogr. Surv. Territories; twelfth annual report for 1878. In two parts. Part II, Pl. XXX, p. 52. Washington, 1883.

Black etching and geological indications.

921 [636*f*].

**1878—Peale** (A. C.), **St. John** (Orestes), **and Endlich** (F. M.). Geological map of portions of Wyoming, Idaho, and Utah. Scale, 8 miles to 1 inch.

Accompanying "Twelfth annual report of the U. S. Geol. and Geogr. Surv Territories, for the year 1878." Maps and panoramas in accompanying pocke sheet 2. Washington, 1883.

922 [636*g*].

**1878—Peale** (A. C.). (Geological map of) Parts of Western Wyomin Southeastern Idaho, and Northeastern Utah. Scale, 4 miles to inch, or 1 : 253,440.

Accompanying "Twelfth annual report of the U. S. Geol. and Geogr. Su Territories, for the year 1878." Maps and panoramas in accompanying pocl sheet 5. Washington, 1883.

923 [636*h*].

**1878—St. John** (Orestes). (Geological map of) Parts of West Wyoming and Southeastern Idaho. Scale, 4 miles to 1 in or 1 : 253,440.

Accompanying "Twelfth annual report of the U. S. Geol. and Geogr. Su Territories, for the year 1878." Maps and panoramas in accompanying pocl sheet 4. Washington, 1883.

924 [763*a*].

**7—Scudder** (S. H.). The Tertiary lake basin at Florissant, Colorado. Scale, 1 mile to 1 inch.

Accompanying "The Tertiary lake basin at Florissant, Colo., between South and Hayden's Parks," U. S. Geol. and Geogr. Surv. Territories; twelfth annual report, for the year 1878. In two parts. Part I, p. 293. Washington, 1883.

Black etching. Reprinted, with additions and alterations, from the Bulletin U. S. Geol. and Geogr. Surv. Territories, Vol. VI, p. 279. Washington, February, 1881.

See **Scudder** (S. H.), 1881—No. 778.

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# ADVERTISEMENT.

(Bulletin No. 8.)

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The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classifications of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization. And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive Departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Williams's Mineral Resources, the Survey has no copies of any of its publications for gratuitous distribution.

## ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map. A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl., 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

## MONOGRAPHS.

So far as already determined upon, the list of the Monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. Published.

IV. Comstock Mining and Miners, by Eliot Lord. Published.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. Published.

VI. Older Mesozoic Flora of Virginia, by Prof. William M. Fontaine. Published.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. Published.

VIII. Paleontology of the Eureka District, Nevada, by Charles D. Walcott. In press.

IX. Brachiopoda and Lamellibranchiata of the Green Marls and Clays of New Jersey, by R. P. Whitfield.

# ADVERTISEMENT.

Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. In preparation.
Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague. In preparation.
Lake Bonneville, by G. K. Gilbert. In preparation.
Dinocerata. A Monograph on an extinct order of Ungulates, by Prof. O. C. Marsh. In preparation.
Sauropoda, by Prof. O. C. Marsh. In preparation.
Stegosauria, by Prof. O. C. Marsh. In preparation.
Of these Monographs, Nos. II, III, IV, V, VI, and VII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by C. E. Dutton, Capt. U. S. A. 1882. 4°. 264 pp. 42 pl. and atlas of 26 double sheets folio. Price $10.12.

III. Geology of the Comstock Lode and Washoe District, with atlas, by G. F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. 1883. 4°. xvi, 464 pp. 29 pl. Price $——.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $——.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 15 pl. Price $——.

Nos. VIII and IX are in press and will soon appear. The others, to which numbers are not assigned, are in preparation.

## BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper, and be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this, each Bulletin will have two paginations, one proper to itself, and one which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 are already published:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining value of Troy ounces of fine metal, &c., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the meridian of 76° 30′, from Tompkins County, N. Y., to Bradford County, Pa., by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A catalogue of geographical maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price — cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. Price 10 cents.

9. A Report of the Work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8°. 74 pp. Price 5 cents.

## STATISTICAL PAPERS.

A fourth series of publications having special reference to the mineral resources of the United States is contemplated. Of that series the first has been published, viz: Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii. 813 pp. Price 50 cents.

Correspondence relating to the publications of the Survey, and all remittances, which must be by postal note or money order, should be addressed to the

DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY,
*Washington, D. C.*

WASHINGTON, D. C., *August* 31, 1884.

DEPARTMENT OF THE INTERIOR

# BULLETIN

OF THE

# UNITED STATES

# GEOLOGICAL SURVEY

## No. 8

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

HURONIAN QUARTZITE OF NEEBISH ISLAND, EAST SIDE ST. MARY'S RIVER. FROM THE WEST.
(The dip is towards the observer.)

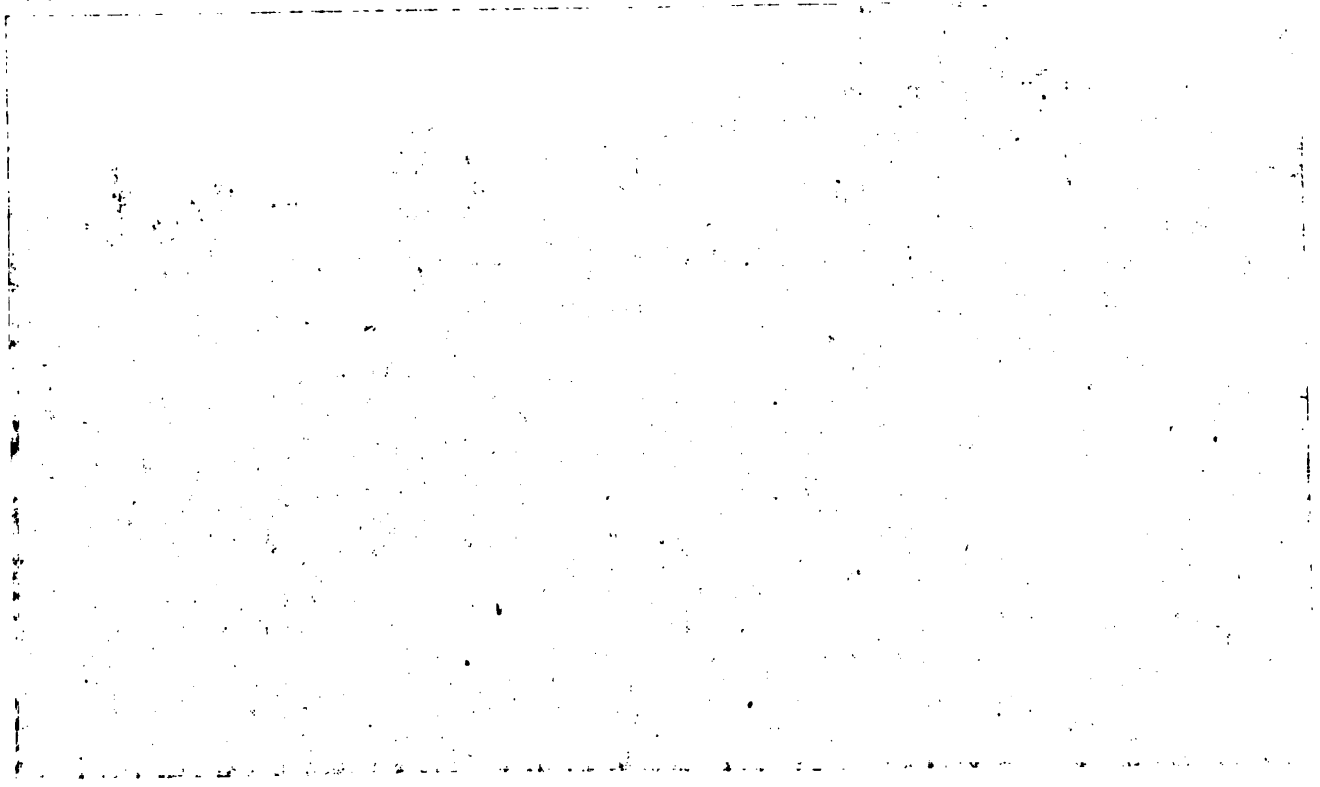
# SECONDARY [illegible]

# MINERAL [illegible]

## CERTAIN [illegible]

R. D. IRVING and C. R. VAN HISE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884



H. LONDAN, ... GAZETTE OF ... ISLANDS, EAST SIDE OF MAUI, S. ... COUNTY OF ... WAII
(Geology ... Quadrangle)

# SECONDARY ENLARGEMENTS

OF

# MINERAL FRAGMENTS

IN

# CERTAIN ROCKS

BY

R. D. IRVING and C. R. VAN HISE

## LETTER OF TRANSMITTAL

UNITED STATES GEOLOGICAL SURVEY,
*Madison, Wis., April* 1, 1884.

SIR: I have the honor to transmit herewith a paper on Secondary Enlargements of Mineral Fragments in Certain Rocks, prepared by myself and Assistant Geologist C. R. Van Hise.

The plates were all drawn from nature with the camera lucida, by Assistant Geologist W. N. Merriam.

I am, sir, very respectfully yours,

ROLAND D. IRVING,
*Geologist in Charge of the Survey of Pre-Cambrian Rocks of the Northwestern States.*

Hon. J. W. POWELL,
*Director United States Geological Survey,*
*Washington, D. C.*

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FIG. 1. Single grain of the sandstone intercalated in Huronian quartzite of East Neebish Island. Enlarged 67 diameters. No. 17 of the list, p. 26. The outlines of the crystal faces were drawn in from a dry mounting, after which the grain was covered with balsam and the nucleal fragment drawn.

FIG. 2. Another grain from the same sandstone, drawn from a balsam mounting. Enlarged 67 diameters.

FIG. 3. Single grain of the Huronian sandstone of Spurr Mountain, Mich. No. 30 of the list, p. 30. Drawn from a balsam mounting. Enlarged 100 diameters.

FIGS. 4, 5, 6. Single grains from the Potsdam sandstone of New Lisbon, Wis. No. 87 of the list, p. 40. Balsam mounting. Enlarged 95 diameters.

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FIG. 1. Indurated Saint Peter's sandstone, Gibraltar Bluff, Columbia County, Wisconsin. No. 96 of the list, p. 42. Polarized light. Enlarged 35 diameters.

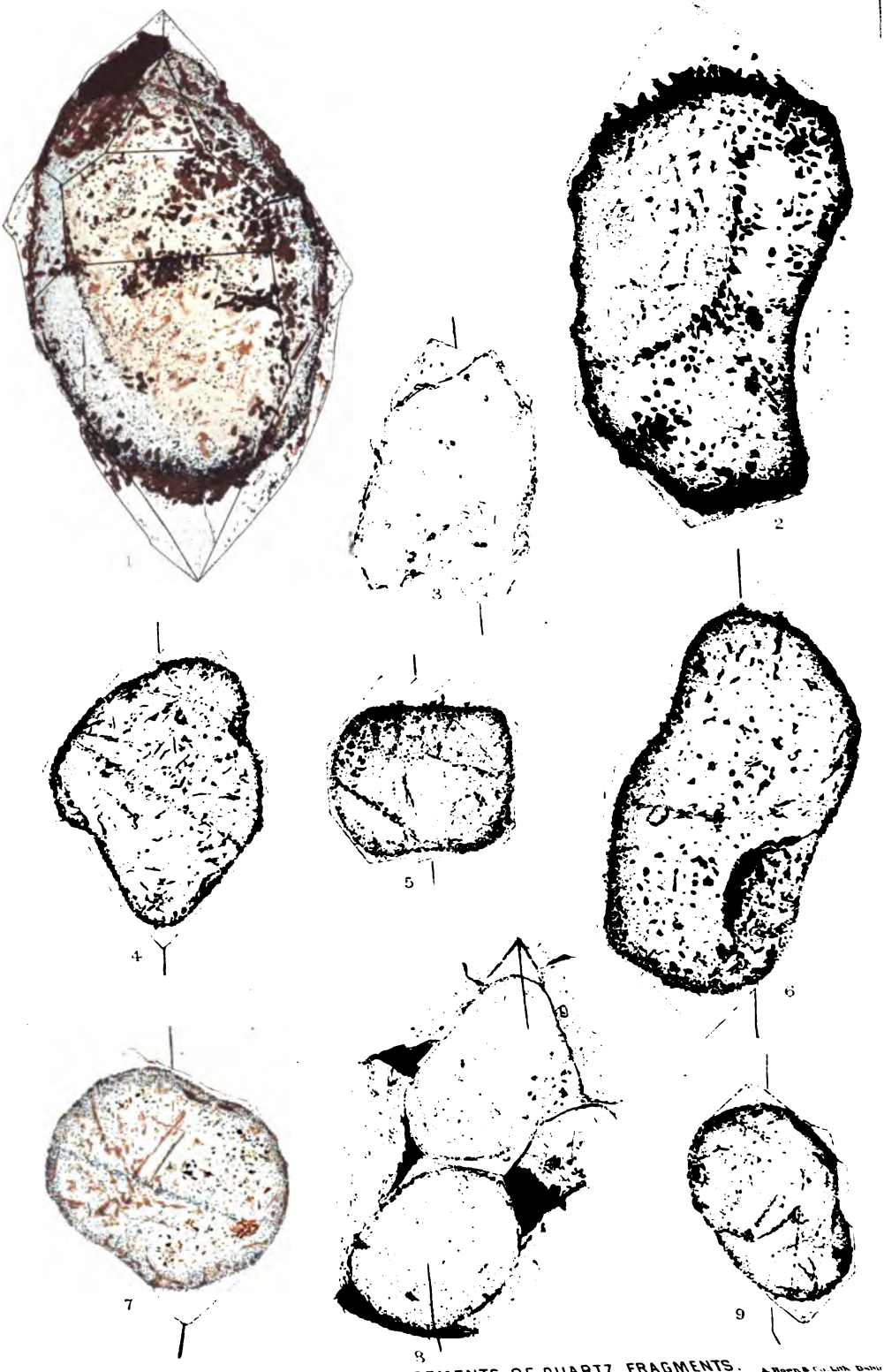
FIG. 2. Huronian quartzite of Neebish Island, Saint Mary's River. No. 12 of the list, p. 25. Polarized light. Enlarged 35 diameters.

the outline of the original grains of sand is perfectly distinct, and the cavities between them are filled with clear quartz in crystalline continuity with the contiguous grains; so that the whole is a mass of interfering crystals, each having a sand-grain as a nucleus. The rock has thus been converted into a hard quartzite, almost like a true quartz rock, but differs from such quartz rocks as those of the Scotch Highlands in containing no mica crystallized *in situ*. All my specimens of these quartz rocks are really highly quartzose mica-schists; and, so far, I have failed in my endeavors to trace the connection between them and true sandstones, though possibly this could be easily done in some districts which I have not examined."[2]

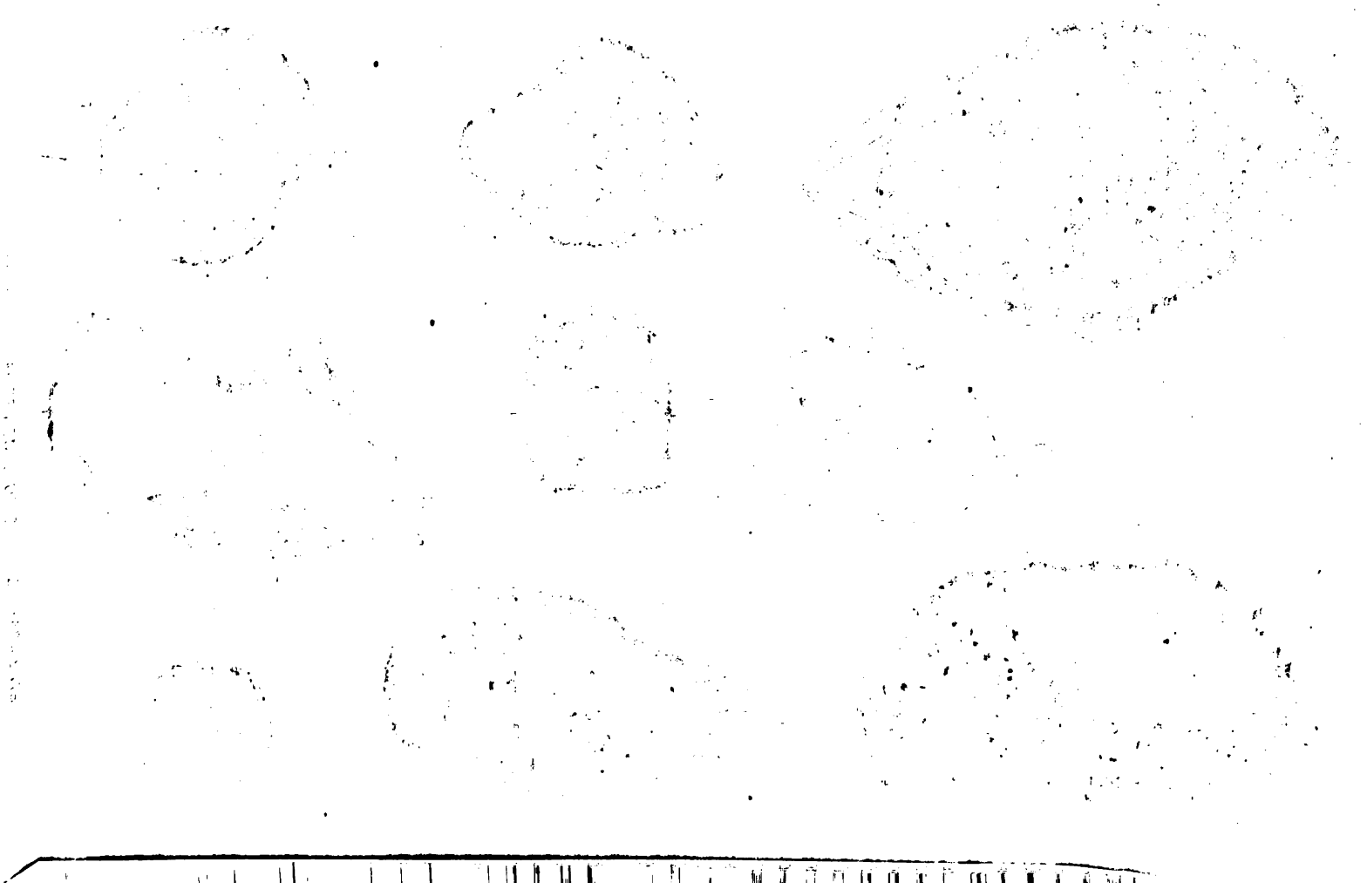
In the American Journal of Science for July, 1881, A. A. Young describes a sandstone from the Potsdam sandstone of New Lisbon, Wis., the rolled grains of which are enveloped in secondary crystal-faceted quartz coatings. In the same journal for June, 1883, the senior author of this paper showed what Sorby regards as probable, viz: that the "cohesion of the grains in hard and compact quartzites" is due to this deposition of interstitial quartz, to be certainly true in the cases of certain quartzites and mica-bearing quartz-schists of Archæan (Huronian) age. He also showed that irregular areas, often of very small size, and even thin crusts, due to a mere weathering, occur frequently in the Saint Peter's and Potsdam sandstones of Wisconsin, in which these sandstones have been changed to vitreous quartzites by the same mode of induration, *i. e.*, by the deposition of an interstitial quartz which has divided itself off into interlocking areas optically continuous with the original grains of quartz sand.

[2] So-called "crystallized" sands and sandstones have been described by many authors, beginning with Gerhard, in 1816, but none of them, so far as we have yet learned, understood that the crystal-faced grains were rolled fragments enlarged by secondary deposition. The idea with regard to these sandstones appears to have been that their crystal-faced grains were wholly separated out from solution, and the sandstones not really of clastic origin. Zirkel (Petrographie, II, p. 575) says of these crystallized sandstones that they "vielleicht gar nicht zu den klastischen Gesteinen gerechnet werden dürfen." See also Naumann's Geognosie, I, p. 530, and Von Cotta's Lithology, Lawrence's translation, pp. 296, 301. Zirkel (Petrographie, II, p. 590) gives a number of references among the older writers, but so far as I have been able to refer to them none seem to have had any idea of the true nature of the crystals.

Daubrée, who described the Vosges crystal-bearing sandstone as long ago as 1852, has quite recently (Études Synthétiques de Géologie Experimentale, 1879, pp. 226–230), in a résumé of earlier observations by himself and others (Elie de Beaumont, Hoffman, Gutberlet, Croisnier) on crystallized sands, stated distinctly his belief in their purely chemical origin. The Vosges sandstone, which is mentioned by Sorby (*loc. cit.*) as an admirable instance of the formation of crystallized sands by the enlargement of rolled grains, Daubrée cites as a typical instance of a sandstone of chemical origin. While admitting the occurrence of instances where it is difficult to see any such connection, he advances the view that, in the cases of the Vosges sand and many others, the deposit of crystals of quartz has been derived from a solution of an alkaline silicate supplied to the sea by the decomposition, before complete cooling, of masses of eruptive feldspathic porphyry, or of porphyry tuffs—a view which receives *no substantiation* from our own observations.




CRYSTAL-FACED ENLARGEMENTS OF QUARTZ FRAGMENTS.



The latter observations were made in the beginning of 1883, but in ignorance of Sorby's results, announced some years before. Several other lithologists had in the mean time made similar observations. In the summer of 1881, Arnold Hague and Iddings noted this form of induration in the Silurian, Devonian, and Carboniferous quartzites of the Eureka district of Nevada, and Mr. Iddings prepared some drawings at the time which will appear in Hague's monograph of that district.[3] Bonney, Phillips, and others have made similar observations in Europe.[4] The peculiar induration due to weathering had also been previously observed both in Europe and in this country,[5] although it does not appear that the exact nature of the induration was in any case understood.

Since the publication, by the senior author of this bulletin, in the American Journal of Science, above referred to, we have been engaged in studying sandstones, quartzites, and other rocks from various formations, with a view of determining how widespread this mode of induration is. Our attention has been mainly turned to rocks of pre-Cambrian age, but, whenever we have been able to procure the material, we have studied also rocks of more recent formations down to the Cretaceous. From the list given below it will be seen that we have found this peculiar form of induration in rocks representing nearly all of the various Huronian areas of the Northwest, as well as in a number of quartzites and sandstones of various degrees of induration from the later formations. We have also noted a number of interesting new points in this connection.

The most important result of our study is, of course, the proving that most, if not all, of the ancient quartzites, as well as many of the quartziferous schists, are composed in the main of the original fragmental material, unaltered save by some of the ordinary metasomatic processes, but the fragments cemented together by a very subordinate quantity of a siliceous cement of secondary origin. This siliceous cement forms the only part of the rock that has crystallized *in situ*, the more or less intricate interlocking of its areas and its common optical continuity with the original quartz fragments giving rise to a deceptive appearance of complete original crystallization.

The least advanced condition of this process of induration is to be met with in sandstones that are quite loose, as was shown by Sorby. The rolled grains of quartz are each furnished with a border of newly deposited quartz, optically continuous with the nucleus, and furnished with more or less perfectly developed crystalline faces. At times the fragment is only partially buried by the newly deposited border, this being especially true of the more irregularly outlined grains, but more

[3] Monographs of the United States Geological Survey, not yet issued.

[4] Q. J. G. S., Vol. XXXIX, p. 20.

[5] A. Geikie, Text Book of Geology, pp. 158, 333. M. E. Wadsworth, Science, Vol. I, p. 146.

usually the grain is completely, though very thinly, covered, so that we have thus formed a quite perfect quartz crystal, whose greater part is, in each case, mainly composed of the old and worn grain. These crystal-faced borders we have observed running in thickness from films so thin as to be barely perceptible with the microscope to those 0.2 or 0.3mm. in width. The presence of these crystal faces makes the surface of the sandstone affected by this induration sparkle and glisten like a frosted surface. Such crystalline sandstones have been known for a long time, and they are common in all formations from the Archæan to the Tertiary. Indeed, since our attention was first drawn to this matter, it has seemed to us as if the presence of at least some of the crystalline faces in quartzose sandstones is rather the rule than the exception. There can be no doubt, we think, that all owe their sparkling appearance to this same process of secondary enlargement of the original fragments. The crystalline faces are best developed, as already said, in loose sandstones, where the induration has not gone far enough to produce much interference, but they may coexist with a considerable degree of induration. The crystal-faced enlargements of the fragments in such sandstones may generally be separated from the nucleal grains by the presence of films of iron oxide on the surfaces of the nuclei, by the greater freedom from inclusions of the newly deposited as compared with the nucleal quartz, by the existence of a roughened surface on the inner grain, and by rows of cavities at the junction of the new quartz with the corroded surface upon which it was deposited.

Cases are met with in which it is exceedingly difficult to separate the two quartzes from each other. Sorby[6] mentions as such an instance the "Gannister" of the South Yorkshire coal field, and in our own experience we have met with two instances, those of the Huronian sandstones of Spurr Mountain, Michigan, and Penokee Gap, Wisconsin, both of which are alluded to in the list given below. The difficulty in all these cases arises from the great relative purity of the original quartz particles and the entire absence of an iron oxide coating to the nuclei, and, in the last two cases at least, from the smallness of the grains; but, in all, careful search discovers grains in which the separating lines may be perceived; and no doubt remains that in these cases also the crystals are enlargements of rounded fragments. These observations are of particular interest, since they render it evident that a completely indurated rock, apparently made up entirely of originally deposited quartz, may yet be only apparently so, the lines of separation between the new and old material being imperceptible.

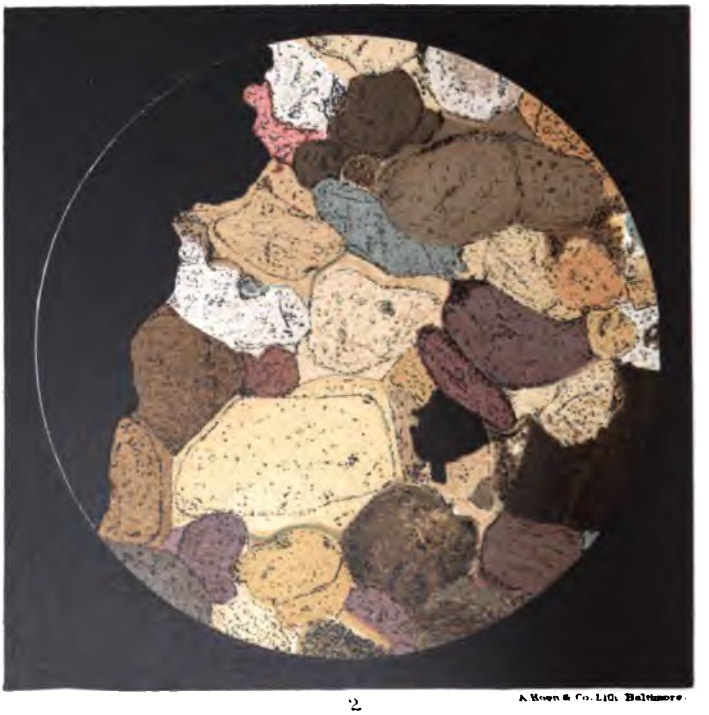
In the very loose sandstones the nuclei and deposited quartz are best distinguished from one another by mounting the sand crumbled from the rock in balsam, while the crystalline faces are best seen in a dry mounting of this sand.

The whole process of enlargement in these crystal-bearing sandstones is of course, as Sorby shows,[7] precisely analogous to what is known to

[6] *Loc cit.*, p. 63.

[7] Loc cit., p. 62.

1



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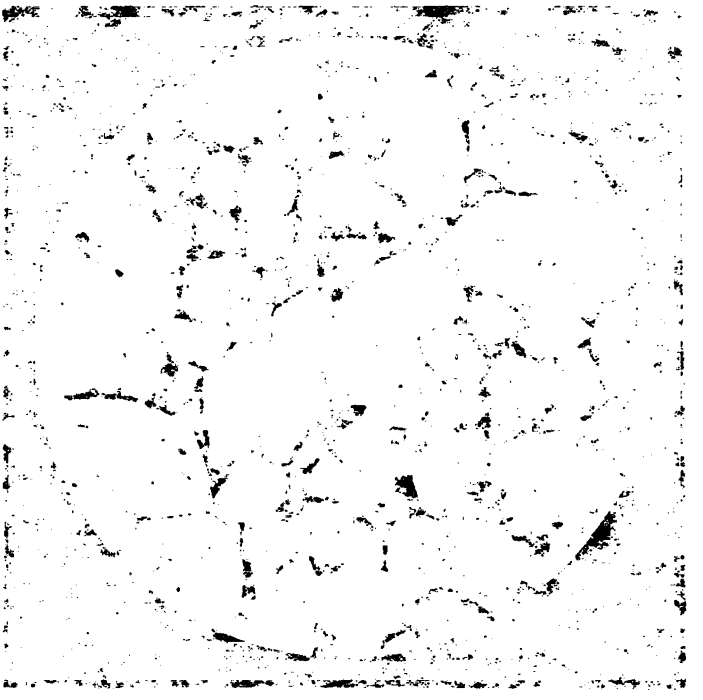
2

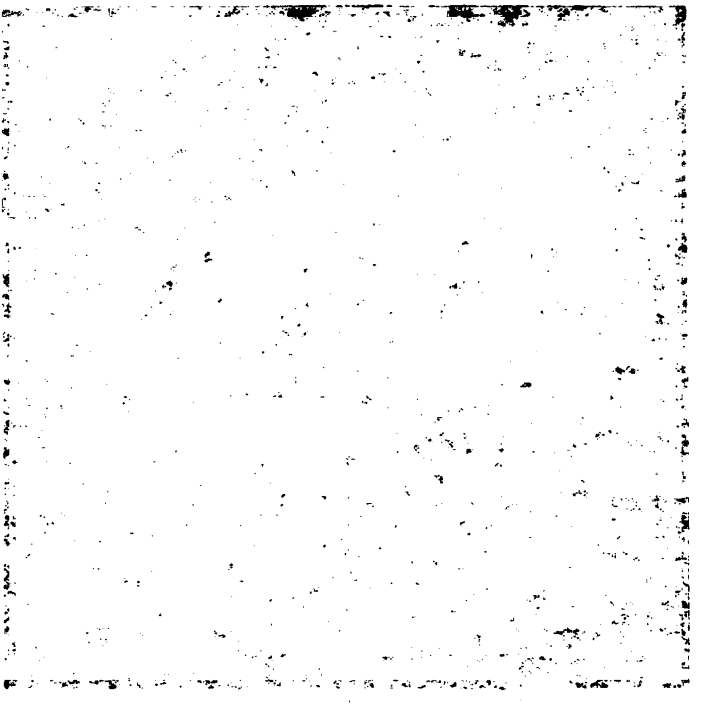
THIN SECTIONS OF QUARTZITES.

instances of localities ... may be mentioned ... Neebish Island, St. Mary's River, ... Marquette, Michigan; ... Ashland County, Wisconsin; ... Minnesota. For Potsdam sandstone.—New Lisbon, Juneau County, Wisconsin; the locality known as Rock Ridge, Adams County, Wisconsin; ... cut on the Chicago and North-western road ... For St. Peter's sandstones—Arlington Prairie, Columbia County, ... Lancaster, Grant County, Wisconsin.

Plate II shows a number of instances of crystal facet enlargements of quartz fragments. Fig. 1 of this plate shows a single grain of the sandstone intercalated in the Huronian quartzite of East Neebish Island, St. Mary's River, enlarged 67 diameters. The outlines of the crystal facets, which are more or less interrupted from lack of material, were drawn from a dry mounting of the grain, after which it was covered in balsam, and the nuclear fragment, with its oxide of iron coating, drawn. Fig. 2 shows another grain from the same sandstone, enlarged ... diameters, as seen in a balsam mounting. Fig. 3 represents a single grain from the Huronian sandstone of Spurr Mountain, Michigan, as seen in a balsam mounting. The enlargement is 100 diameters. Figs. ... and 6 show the appearance, in the balsam mounting, of single grains from the Potsdam sandstone of New Lisbon, Wisconsin, enlarged ... diameters. Figs. 7 and 9 are similarly mounted single grains from Potsdam sandstone of the quarry on the Torch Lake Railroad, Keweenaw Point, Michigan, enlarged 67 diameters. Fig. 8 is a portion of a thin section of the same sandstone, also enlarged 67 diameters, and ... as seen between the crossed nicols, with the object of showing that the nuclear fragments and enlargements polarize together. The lines on two of the grains in this figure indicate the positions of the elasticity axes. The black spaces are holes in the section.

... the layer described in the Wisconsin reports under the name of the Madison ... The occurrence of crystal-faceted grains in the more siliceous and looser ... of this layer appears to be an all but universal phenomenon in Southern Central Wisconsin.





THE REGIONS OF SCARLET

occur when a crystal of a soluble salt is placed in an evaporating saturated solution of the same substance. We have tried this experiment with fragments, from one-eighth inch to one-half inch in diameter, of alum ($K_2 Al_2 (S O_4)_4$), nickel ammonium sulphate ( $(N H_4)_2 Ni (S O_4)_2$,) and sodium and potassium tartrate ($Na K (C_4 H_4 O_6)$.) The fragments in each case were thoroughly rounded and coated with iron oxide. Being then hung each in its appropriate solution, the angles and faces were soon rapidly developed, after which the crystal continued to grow over the whole surface. Sections made from these crystals showed the nuclei bounded by oxide of iron films and built out by newly deposited material with precisely the relations met with in the enlarged grains of crystal-bearing sandstones.

As instances of localities yielding sandstones with crystal-faceted grains may be mentioned the following: For Huronian sandstones—East Neebish Island, St. Mary's River, Canada; Spurr Mountain, Michigan; Penokee Gap, Ashland County, Wisconsin; Devil's Lake, Sauk County, Wisconsin; Redstone, Nicollet County, Minnesota. For Potsdam sandstone:—New Lisbon, Juneau County, Wisconsin; the great bluff known as Roche Écrit, Adams County, Wisconsin, and the railroad cut on the Chicago and Northwestern road just south of Madison.[8] For St. Peter's sandstones—Arlington Prairie, Columbia County, Wisconsin; Lancaster, Grant County, Wisconsin.

Plate II shows a number of instances of crystal-faced enlargements of quartz fragments. Fig. 1 of this plate shows a single grain of the sandstone intercalated in the Huronian quartzite of East Neebish Island, St. Mary's River, enlarged 67 diameters. The outlines of the crystal faces, which are more or less interrupted from lack of material, were drawn in from a dry mounting of the grain, after which it was covered with balsam, and the nucleal fragment, with its oxide of iron coating, drawn. Fig. 2 shows another grain from the same sandstone, enlarged 67 diameters, as seen in a balsam mounting. Fig. 3 represents a single grain from the Huronian sandstone of Spurr Mountain, Michigan, as seen in a balsam mounting. The enlargement is 100 diameters. Figs. 4, 5, and 6 show the appearance, in the balsam mounting, of single grains from the Potsdam sandstone of New Lisbon, Wisconsin, enlarged 95 diameters. Figs. 7 and 9 are similarly mounted single grains from the Potsdam sandstone of the quarry on the Torch Lake Railroad, Keweenaw Point, Michigan, enlarged 67 diameters. Fig. 8 is a portion of a thin section of the same sandstone, also enlarged 67 diameters, and drawn as seen between the crossed nicols, with the object of showing how the nucleal fragments and enlargements polarize together. The black lines on two of the grains in this figure indicate the positions of the elasticity axes. The black spaces are holes in the section.

[8] This is the layer described in the Wisconsin reports under the name of the Madison sandstone. The occurrence of crystal-faceted grains in the more siliceous and looser portions of this layer appears to be an all but universal phenomenon in Southern Central Wisconsin.

A more advanced condition of induration is met with in certain sandstones, which, while still showing to some extent the crystalline facets, have the secondarily deposited quartz areas more generally interfering with one another. This may be seen in much of the Huronian quartzite at Neebish, Saint Mary's River; Redstone, Minn.; and Devil's Lake, Wis.—at all of which localities may be seen rapid transitions from the loosest sandstone to the most compact and vitreous quartzite, as also in much of the Potsdam sandstone of the interior of Wisconsin, for instance the rock quarried at Grand Rapids, Black River Falls and Packwaukee. Fig. 1 of Plate III is drawn from a section of the vitrified crust of the St. Peter's sandstone of Arlington, Columbia County, Wisconsin. This crust, which is decribed somewhat fully on a subsequent page, is immediately below the surface without crystalline facets, the enlargements having interfered too thoroughly. But at a depth of one-fourth to one-half an inch the crystal facets begin to grow plentiful, until the loose sandstone is reached at the depth of about an inch or two, when every grain is furnished with the facets. The figure referred to shows one of the intermediate phases where there has been some interference, but crystal facets have been enabled to form in a number of places. The outlines of the nucleal grains are distinctly but not strongly marked. The brown filling material is oxide of iron.

A still more advanced stage of induration, but yet one which is still short of complete vitrification, is met with in those quartzites, which, while retaining something of a granular or arenaceous appearance, are yet without any of the crystalline facets, the interference of the secondary quartz areas having been general. An excellent instance of this is the sandstone from Gibraltar Bluff, Columbia County, Wisconsin. Much of a similar material occurs in the Huronian quartzites of the north shore of Lake Huron, of Marquette, Mich., and of Southwestern Minnesota. The Gibraltar Bluff rock is shown at Fig. 1 of Plate V, which represents part of a thin section, as seen in the polarized light, enlarged 35 diameters. A more arenaceous quartzite, but still one without crystal faces, is shown at Fig. 2, Plate III, which represents a thin section of the sandy Animikie quartzite of Portage Bay Island, Minnesota. The enlargement is 45 diameters, and the section is represented as seen in the polarized light. It will be noted that the enlargements of the grains are at times unusually broad.

In the most completely vitreous quartzites the arenaceous or granular appearance is entirely lost, the particles being fused into an apparently homogeneous mass, which appears both to the naked eye and under the microscope to be wholly composed of originally deposited, intricately interlocking areas of quartz. But closer study of the sections of such quartzites shows that, like those previously described, they are made up partly of fragmental material and partly of a secondarily deposited

quartz, the interlocking areas of the latter being in large measure optically continuous with the original fragments, but also at times in part independent of them. The degree of intricacy of the interlocking of the areas of the secondary quartz will be found to vary greatly in different quartzites. At times these areas will meet each other along quite straight or only slightly curved lines, and again they will dovetail into each other in the most intricate manner. As a type of the most completely vitrified quartzites, may be mentioned the "gannister" of Marquette, Mich., No. 22 of the list below. A thin section of this rock, as seen in the polarized light, and enlarged 31 diameters, is represented in the upper half of Fig. 1, Plate VI. It will be seen that the enlargements are often unusually broad and dovetail with each other somewhat intricately. Other vitreous quartzites are shown at Fig. 2, Plate V; Figs. 1 and 2 of Plate IV, and the upper half of Fig. 2 of Plate VI. The last three of these figures represent the red Animikie quartzite of Prarie River Falls, Minnesota. The rock of this place is described as being much of it sandy, but the specimen furnished us by the kindness of Prof. N. H. Winchell shows a quartzite in which but little of an arenaceous texture remains. Two of the figures are drawn from the section as seen in the polarized light, in order that the extent of the enlargements may be seen. It will be observed that in places they dove-tail quite intricately and the outlines of the very round nucleal fragments are rendered beautifully distinct by the fringes of oxide of iron.

The proportion of the infiltrated quartz which has crystallized independently of the original fragments varies very greatly in different cases. At times most of it, or even all, seems to occur in this form, the interstices between the much-rounded fragments being entirely filled with a secondary quartz in minute intricately interlocking areas, wholly independent of the original grains. As instances of rocks in which the independent deposition of quartz is the chief or only indurating material, may be mentioned the foot-wall rock of the Champion Mine, Michigan, much of the quartzite of the great range immediately east of Marquette, Mich., and the red quartzite of McClennan's Landing on the north shore of Lake Huron. From these extreme cases there are all phases down to the cases where all of the secondary quartz occurs as enlargements of the original fragments.

Thin sections of quartzites in which the fine interstitial quartz is present are not easily represented by figures. At the lower half of Fig. 1, Plate VI, an attempt is made to represent the Huronian quartz-schist from near Marquette. The section is drawn as seen in the polarized light and is enlarged 36 diameters.

In some cases where the enlargements of the original grains and the independently oriented quartz occur together, the enlargements present the appearance of fading out gradually into the finely interlocking interstitial material. This appearance arises from the fact that as the original fragment is receded from, less and less of the interstitial quartz

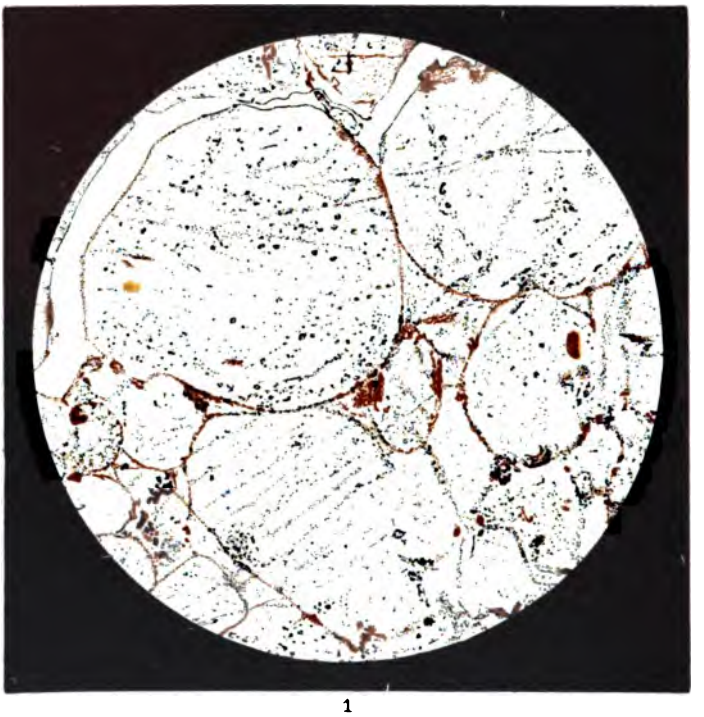
the Penokee Huronian.[14] This member of the Penokee series is plainly the equivalent of the upper mica-schist member of the Marquette Huronian.[15] The latter mica-schist is finely displayed among the islands at the outlet of Michigamme Lake, where it is often plainly of an arenaceous appearance, but so far our sections have failed to prove the existence of secondary enlargements of quartz fragments in them, although what appears distinctly to be fragmental quartz is seen in these sections. The larger part, however, of the quartz present is fine and clear, so that it is difficult to determine whether it is wholly an originally deposited quartz or is a finely fragmental material, the particles of which are now so enlarged as to interlock.

A general fragmental appearance is not uncommon in the mica-schist sections that we have examined, while the presence, in some kinds at least, of very strongly marked and unmistakable sedimentary deposition bandings traversing the schistose or slaty cleavage directions is sufficient proof that in such cases the material is mainly of fragmental origin. But so far as our investigations have progressed we have only in a few cases been able to prove the enlargement of quartz fragments by secondary deposition. It seems probable, however, that in many cases where their existence cannot be proved the enlargements exist. In such cases we may suppose that they cannot be seen simply because of the absence of a bordering material or of roughened surfaces to the original fragments. None of the mica-schists above referred to are like those which approach the gneisses in character. The latter have often as a characteristic feature large flattened areas of quartz lying in the planes of foliation. We have not as yet examined any such rocks in this connection.

Below we give a list of the various localities of rocks in which we have discovered the secondary enlargements of quartz fragments. The induration of the rocks of these places is in most cases mainly due to the presence of these secondary enlargements, the remainder of the material being fragmental, but cases are included where, as explained above, the indurating silica has been separated out in part independently. The list does not represent nearly all of the sections in which this indurating quartz has been found. Often a number of sections from the rocks from one general neighborhood have been examined, but the locality is only referred to once. We have classified the localities (1) according to the general position of the rocks in the geological series; (2) according to geographical distribution; and (3) according to the lithological characters. Brief descriptive notes are added in each case.

[14] Geology of Wisconsin, pp. 145–149.

[15] Geological Survey of Michigan, Vol. I, p. 113. Geology of Wisconsin, Vol. III, p. 165.



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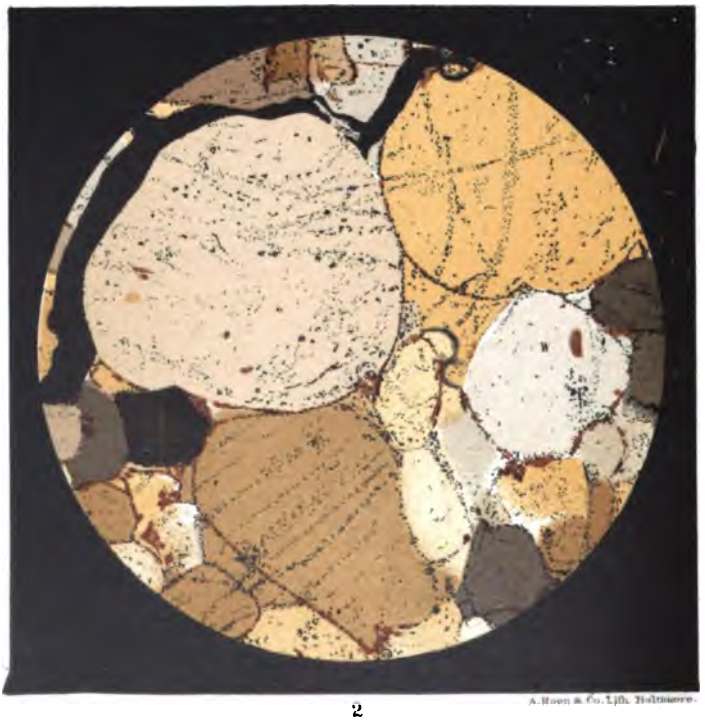

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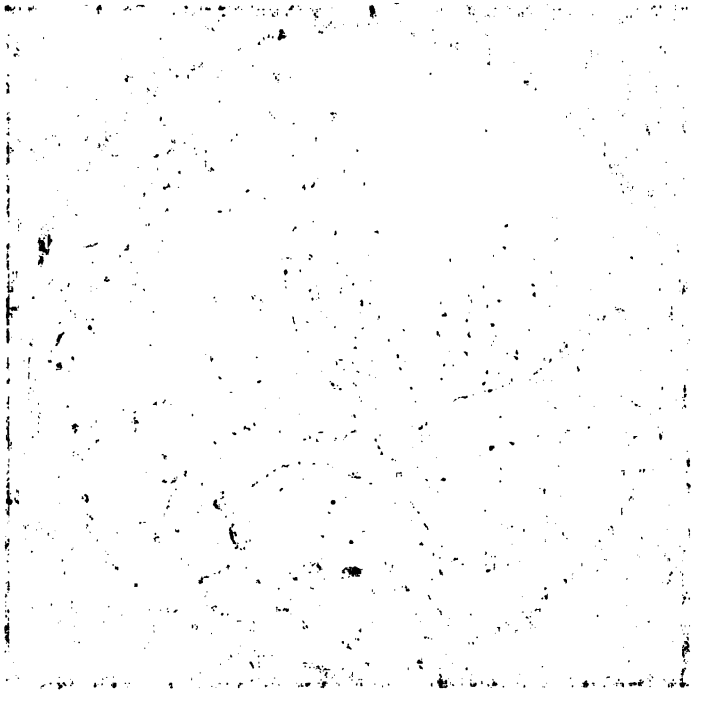
THIN SECTION OF RED QUARTZITE



## List of Localities.

### *HURONIAN ROCKS.*

#### IN THE TYPICAL HURONIAN REGION OF LAKE HURON.

*A.—Vitreous Quartzites.*

**1. Island two miles east of Thessalon Point, north shore of Lake Huron. (Logan's "3 a," "Grey Quartzite."[14])**

A feldspathic quartzite, holding many granite pebbles and boulders. Rounded to angular fragments of quartz, orthoclase, and oligoclase, with a fine interstitial material, partly of the same nature and partly kaolinitic, make up most of the rock, but the induration is plainly due to secondary enlargements of the quartz fragments, the enlargements being narrow, and not interlocking intricately. In places the angularity and abundance of the feldspar fragments, the occurrence of granite fragments, including both feldspars and quartz, and the presence of the secondary enlarging silica, produce a rock which is macroscopically and microscopically similar in appearance to granite or gneiss. (Slides 1071 to 1079 inclusive.)

**2. Islands 3½ miles northwest of Thessalon Point, north shore Lake Huron. (Logan's "3 c," "White Quartzite.")**

A feldspathic quartzite. Quite intricately interlocking quartz areas make up the larger part of the rock, but the interlocking is plainly due to the enlargement of rounded fragments, whose outlines are here and there plainly to be seen. There is also much of a fine interstitial independently deposited silica, which here and there approaches very close to, if it does not reach, the amorphous form. (Slides 1183, 1184.)

**3. Mainland, four miles northwest of Thessalon Point, north shore Lake Huron. (Logan's "3 c," "White Quartzite.")**

A vitreous, white to brown quartzite conglomerate, in which the pebbles, 1 to 2 inches in diameter, are of white quartz and black chert, with rarer ones of red jasper. The matrix is composed of the same materials, along with fragments of feldspars. The induration has been chiefly by enlargement of the quartz fragments, among which are some originally complex. These have taken complex enlargements. The bounding lines of the original quartz fragments are only now and then perceptible. The larger pebbles of quartz do not seem to have taken any enlargements. There is also some fine independently deposited interstitial silica and a good deal of interstitial clayey material and flakes of chlorite, the latter probably a result of metasomatic change of the feldspars. (Slides 1185 to 1188 inclusive.)

**4. Islands off east side Bruce Mine Bay, Lake Huron. (Logan's "3 c," "White Quartzite.")**

A light-colored feldspathic quartzite, much like the last described, but with these differences: the quartz areas interlock much more intricately; the division lines between the original grains and enlargements are still more rarely visible, being plain in only two or three out of some twenty sections; the feldspars are much more abundant, and include microcline and plagioclase, as well as orthoclase. This rock has plainly received a larger quantity of siliceous cement than the last described. The abundance of feldspars, the presence of plagioclases, the intricate enlargements produced by secondary quartz, and the presence of much chlorite as a result of the alteration of the feldspars, all combine to produce a strong resemblance to some gran-

([16]) See Atlas to Geology of Canada, 1863, Plate III, for Logan's subdivisions of the original Huronian.

itic rocks. The specimens are mostly taken from the neighborhood of some of the numerous dikes with which the rock is riddled, which may possibly have something to do with the large amount of siliceous cement and the consequent granitic appearance presented by this rock. (Slides 1191, 1192, 1194, 1196, 1197, 1201 to 1205 inclusive.)

5. North side of Campement d'Ours Island, Lake Huron. (Logan's "3 f," "Upper Slate Conglomerate.")

A red feldspathic quartzite, the feldspars including both orthoclase and plagioclase, the two together making up fully one-half of the rock. The quartz fragments are much enlarged, the enlargements interlocking with each other and with the feldspars somewhat intricately. There are present interstitially kaolin, chlorite, and oxide of iron, but only a very little fine secondary quartz. (Slide 1224.)

6. South side Campement d'Ours Island, Lake Huron. (Logan's "3 f," "Upper Slate Conglomerate.")

A feldspathic quartzite, the feldspars including both orthoclase and oligoclase, but not nearly so plenty as in the rock last described. The quartz fragments are very much enlarged, so as to interlock intricately. The lines of division between the enlargements and the original fragments are only rarely satisfactorily seen, some sections being quite without them. That the interlocking quartz areas of this rock are due to enlargement of quartz fragments would never be suspected but for their previous discovery in other similar rocks and in other parts of this same layer. Only a very small quantity of the interstitial quartz in this rock appears to have crystallized independently of the original fragments. (Slide 1226.)

A number of rocks on the west and south sides of Campement d'Ours, belonging with the same member of the series as the above, were examined, and all showed essentially the features above noted.

7. North shore of Lake Huron, two miles east of McClennan's Landing. (Logan's "3 f," "Upper Slate Conglomerate.")

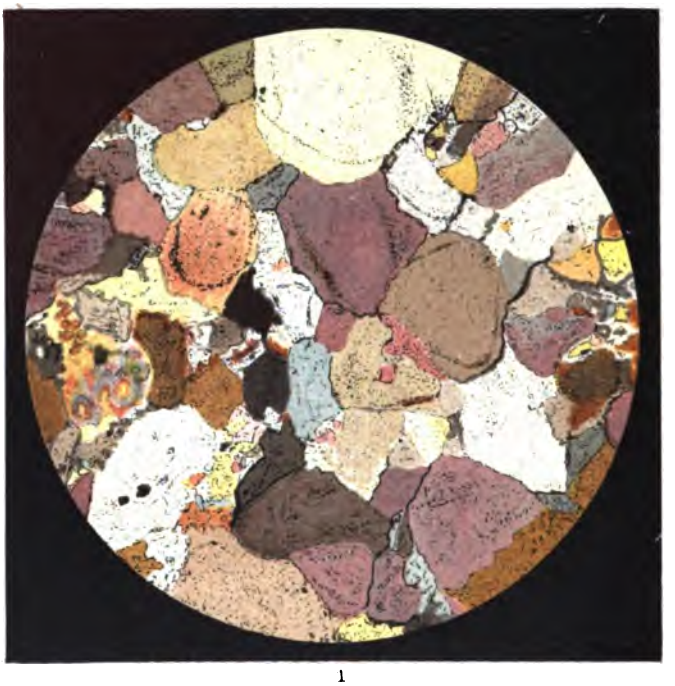
A purple, vitreous, non-feldspathic quartzite, composed chiefly of rounded quartz grains, which have rarely, if ever, received any enlargement, and consequently do not interlock. Interstitially finely-divided secondary silica has been deposited, in part in an amorphous form. There is also a good deal of kaolinic material in the interstices. The presence of this material and also of a small quantity of iron oxide and the absence of enlargements give the sections of this rock just the appearance of those of an ordinary sandstone. Nevertheless it is much indurated, and the induration is plainly due to the independent secondary deposition of interstitial silica. (Slide 1233.)

8. McClennan's Landing, north shore of Lake Huron. (Logan's "3 g," "Red Quartzite.")

A light-red, non-feldspathic quartzite. This rock is a good deal like the last described, the induration being mainly due to the independently oriented interstitial silica, but the quartz fragments are, for the most part, somewhat enlarged. (Slide 1238.)

9. Two miles west of McClennan's Landing, north shore of Lake Huron. (Logan's "3 k," "Red Jasper Conglomerate.")

A white quartzite, made up chiefly of quite large quartz grains, all of which are more or less enlarged, though the bounding lines of the original fragments are only here and there perceptible. There is, however, not much interlocking of the quartz enlargements, there being a good deal of interstitial material in the shape of kaolin, muscovite scales, and finely-divided quartz. (Slide 1239.)



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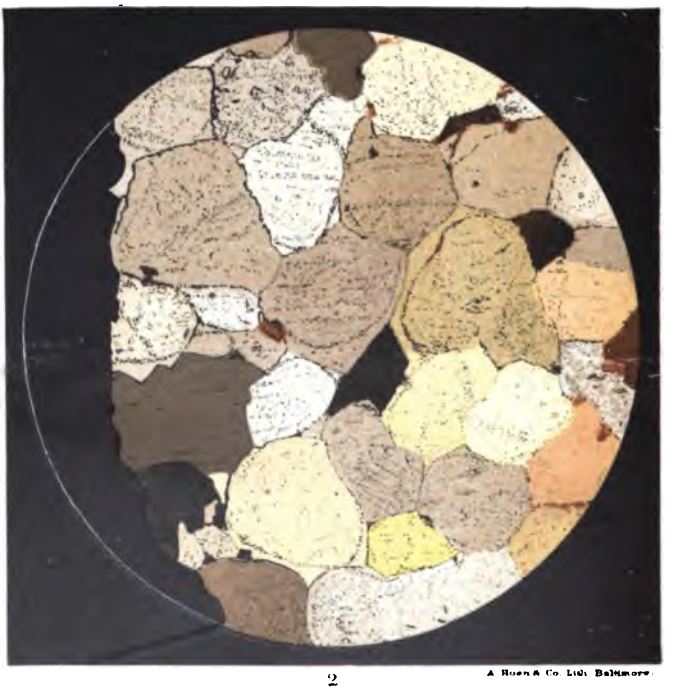

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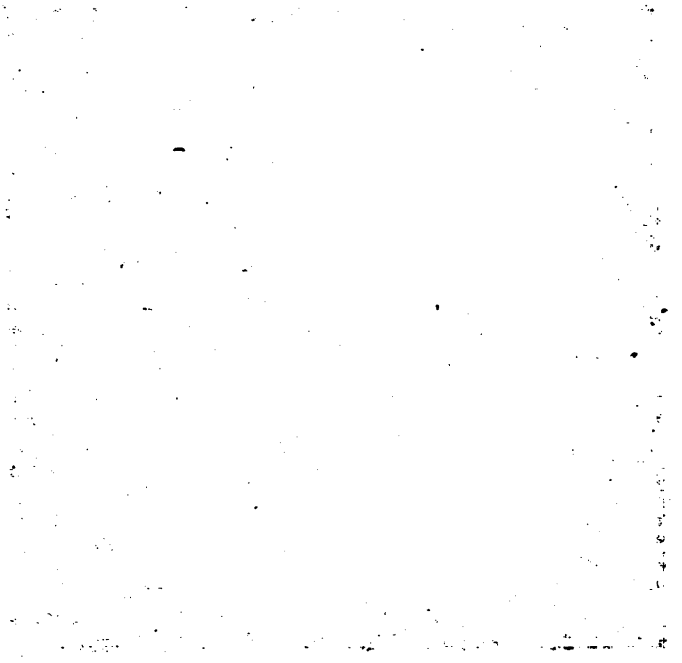
A. Hoen & Co. Lith. Baltimore.

THIN SECTIONS OF SANDSTONE AND QUARTZITE.



### 10. Near the mouth of Echo River, Canada side of Lake George, Saint Mary's River. (Logan's "3 h," "Red Jasper Conglomerate.")

A conglomeratic quartzite composed chiefly of clear quartz pebbles, one-fourth to one-half inch in length, with rarer ones of red jasper. These are imbedded in a fine, much-indurated matrix, apparently composed of the same materials. Under the microscope the matrix is seen to be composed of finely-divided, perhaps sometimes amorphous silica, with kaolinic material and oxide of iron. The quartz fragments are enlarged, but never so much as to interlock with one another, and the outlines of the original grains are often imperceptible. Some of the large quartz areas appear to fade away into the fine matrix in the manner described on a previous page. This appearance is plainly due to the fact that, as the enlargement of the grain progressed, it became more and more difficult to thrust aside the clayey matrix, more and more of which was consequently included within the enlargements, more and more of the secondary silica at the same time departing from its allegiance to the original grain and depositing independently. (Slide 1242.)

### 11. North shore of St. Joseph's Island, Lake Huron. (Logan's "3 i," "White Quartzite.")

A gray, non-feldspathic quartzite. The induration is principally due to the enlargements of the original grains, which sometimes interlock closely, but in places there is a good deal of a fragmental matrix of kaolinic material, including muscovite scales, in which cases the grains sometimes appear to fade away into the matrix, as described in the preceding. The outlines of the original grains are often quite distinctly seen. (Slide 1228.)

### 12. East Neebish Island, St. Mary's River. (Logan's "3 i," "White Quartzite.")

A light gray to white quartzite. At times completely vitrified and without any trace of a fragmental appearance, but in other places a loose sandstone, with crystal faceted grains, there being every possible phase between those two extremes. In the thin section, the most completely vitreous kinds are found to be made up wholly of enlarged quartz fragments, there being none of the independently deposited interstitial silica or of any other interstitial material. The quartz areas interlock intricately, the outlines of the original fragments being everywhere strongly marked. In sections of the less completely vitreous kinds, a fine interstitial silica is to be seen in greater or less quantity. Some of the quartz fragments present the appearance of graduation into the matrix, due to the gradual change in the depositing silica from dependence upon the original fragments to independence of them. Fig. 2, Plate V, is drawn from the East Neebish quartzite. The arenaceous varieties of the East Neebish rock are noted below in another connection. (Slides 1019 to 1024, inclusive.)

### 13. Rocky islets in Saint Mary's River, northwest of Saint Joseph's Island, Lake Huron. (Logan's "3 i," "White Quartzite.")

These islands show a gray quartzite similar to that of Neebish Island. (Slides 1025, 1028.)

### 14. McDonald Township, six miles east of Saint Mary's River, Canada. (Logan's "3 i," "White Quartzite.")

A white, completely vitreous quartzite, entirely similar to the most vitreous phase of the Neebish quartzite. The outlines of the original fragments are everywhere very plain in this section. (Slide 1240.)

15. From near the mouth of Echo River, Canada side of Lake George, Saint Mary's River. (Logan's "3 i," "White Quartzite.")

A completely vitreous quartzite, similar to that of Neebish Island, except in having a very small quantity of intrestitial kaolinic material. (Slides 1245, 1246.)

### B.—*Schistose quartzites.*

16. Islands two miles southeast of Neebish Rapids, Saint Mary's River. (Logan's "3 i," "White Quartzite.")

Light-gray, argillaceous, schistose quartzites, differing from the non-schistose quartzites above described in containing a very large amount of a clayey matrix, and in the schistose structure. The rather unusually large quartz fragments are wholly separated from one another by the matrix, and, as is generally the case when there is much of a clayey matrix, the enlargements are but slight. Some of the quartz fragments are complex, and appear to have received complex enlargements. (Slide 1031.)

### C.—*Sandstones.*

17. East Neebish Island, Saint Mary's River. (Logan's "3 i," "White Quartzite.")

Intercalated in and grading into the vitreous quartzite above described (No. 12) is a reddish, very coarse-grained, feebly indurated sandstone, each one of the grains being furnished with crystal faces from secondary enlargement. The crystal faces are in this case very much larger than in any other case that we have yet noted. Some of the grains, each a single quartz individual, reach as much as one-fourth inch in diameter, and have crystal faces of correspondingly large size, while half the mass of the rock is composed of grains which exceed one-sixteenth inch in diameter. Occasionally some of these grains are complex, but most of them are single individuals. The oxide of iron cement is very abundant, and the secondary enlargements of the grains have always between them and the original surfaces a heavy border of the iron oxide. Fig. 2, Plate II, represents one of these grains broken by hand from the rock, as seen in a balsam mounting enlarged 67 diameters. The crystal facets bounding the grain are not seen on this mounting, but only the rough, iron-stained surface of the original grain and the outlines of the pellucid enlargement. Fig. 1 of the same plate shows the positions of the crystal faces upon another grain, the positions of the faces having first been drawn in with the camera from a dry mounting, after which, without altering its position, the fragment was covered with balsam, and the kernel drawn in its position within the crystal. The very slight coherence of this rock as compared with the completely vitreous quartzite into which it grades within a few inches, is plainly to be attributed to the relatively coarse character of this rock, and to the supply of indurating quartz not having here been sufficient to fill out the large-sized interstices, and its having consequently developed crystalline faces. (Slide 1391.)

### D.—*Graywackes.*

18. Palladreau Islands, north shore Lake Huron. (Logan's "3 d," "Lower Slate Conglomerate.")

A very dark greenish-gray, nearly black, fine-grained, compact rock, having an aphanitic matrix, in which are scattered minute particles of quartz and feldspar. Except for very sparsely scattered granite and porphyry pebbles, the appearance is more that of a very fine-grained porphyritic green-stone than that of a clastic rock. The clastic nature is, however, very evident in the thin section, which shows a ground-mass composed very largely of kaolin and chlorite, mingled with fine particles of feldspar and quartz, with more or less brown oxide of iron and magnetite.

The kaolin and chlorite are evidently the results of the alteration of the feldspathic portion of the matrix. Thickly scattered through this matrix are larger fragments of quartz and feldspar, between which and the particles of the matrix there is every gradation in size. The feldspars include both plagioclase and orthoclase. The rounded quartz fragments here and there show narrow enlargements, and also the gradual fading away into the matrix which is characteristic of rocks where there is much of a finely fragmental matrix. It is possible that some of the induration has been produced by the independent secondary deposition of fine silica, but it seems to be largely due in this case to the chloritic alteration of the matrix. (Slide 1032.)

### 19. From the mainland, four to five miles east of Campement d'Ours Island Lake Huron. (Logan's "3 f," "Upper Slate Conglomerate.")

The specimens collected from the "Upper Slate Conglomerate," as exposed along the north shore of Lake Huron, between the French Islands and Campement d'Ours, are chiefly of rocks nearly allied to the last described, though including also some true vitreous quartzites, some of which have been above alluded to, and between which and the predominating graywackes there is a complete gradation. A part of the rock is very highly conglomeratic, with pebbles of granite, felsitic porphyry, and jasper, but in other portions the pebbles are wanting, or are very sparse and small. These present a great variation in coarseness, the finest kinds being contorted clay-slates, but they are all composed of essentially the same materials as noted in the slate conglomerate from the Palladrean Islands above described, like which they are all dark colored from the presence of much chlorite. Enlargements of the quartz fragments are generally to be made out, and, at least in those kinds which are more distinctly quartzitic, much of the induration is due to the enlargements. Induration seems also to have been produced by the deposition of a fine interstitial quartz, and a chalcedonic or amorphous silica. The feldspar grains, including both orthoclase and plagioclase, also often present an appearance which suggests that they too have been enlarged by second growths. Sharp lines of division between the supposed enlargements and the original nuclei, as seen so often in the case of enlarged quartz fragments, we did not satisfactorily make out; but in many instances the outer portion of the grain is relatively undecomposed and free from inclusions, as compared with the nuclei. This appearance, taken together with the fact that secondary enlargements of feldspar fragments have been proved to occur in certain Keweenawan sandstones, lead us to believe that we have them here also.[17] All of these rocks carry a very large amount of a green chloritic mineral, which has plainly been produced from the feldspars by a metasomatic process.

These graywackes are all typically "recomposed" rocks, and while plainly fragmental, are no more so than many kinds that are classed as crystalline schists. The enlargement of the quartz and feldspar grains, the production of abundant chlorite, the presence of much feldspar, and the secondary deposition of an interstitial silica certainly would have to be carried but little further to give us a rock in which it would be exceedingly difficult to detect the presence of the detrital material. (Slides 1215 to 1218.)

#### IN THE IRON-BEARING SERIES OF MARQUETTE, MICH.

#### A.—*Vitreous quartzites.*

### 20. Quartzite range, south of Marquette, near shore of Lake Superior, (N.W. ¼, Sec. 6, T. 47, R. 24 W., Michigan). (Brooks's "Formation V," "Lower Quartzite.")

A bright-red vitreous quartzite, composed almost wholly of interlocking areas of quartz, which are all taken to have been produced by the enlargement of fragmental

[17] See Part II of this bulletin; also American Journal Science, May, 1884, p. 399.

nuclei, since in a number of them the outlines of these nuclei are plainly recognizable. The red color of the rock is due to the presence of a small quantity of red oxide of iron. (Slide 1009.)

### 21. Shore of Lake Superior, two and a half miles southeast of Marquette, (SE. ¼, Sec. 36, T. 48, R. 25 W., Michigan). (Brooks's "Formation V," "Lower Quartzite." [18])

This is the locality of the unconformable contact of the Lake Superior sandstone and Huronian quartzite, made classical by Foster and Whitney. A white, strongly vitreous quartzite. The induration appears to be almost wholly due to the interstitial deposition of fine quartz, the original outlines of the quartz fragments coinciding for the most part with the outlines as now seen of the individual areas. There is a little kaolinic interstitial material. (Slide 1013.)

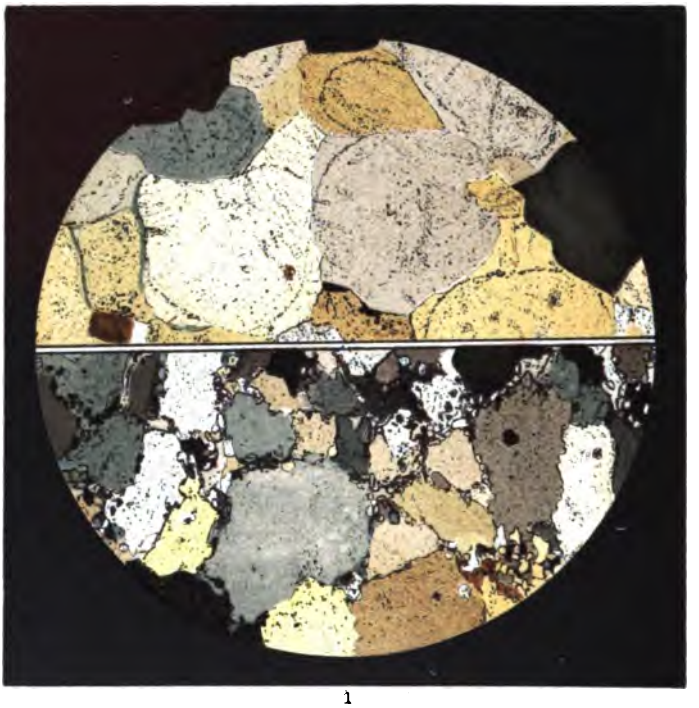
### 22. Gannister quarries, north and south sides of Carp River, near Marquette (Secs. 35 and 36, T. 48, R. 25 W., Michigan.) (Brooks's "Formation V," "Lower Quartzite.")

Light-gray, highly translucent, completely vitrified quartzites. These rocks are composed almost wholly of quartz, there being a very minute quantity in some of the interstices of kaolinic material. Although coming from the same vicinity and layer as the rock last described, and not differing very much from it microscopically, we have in these rocks a case where the induration and vitrification are wholly due to secondary enlargement of the original fragments. The outlines of the nucleal grains are usually very distinct, and the enlargements interlock quite intricately, so that, as seen in the polarized light, this rock seems to be completely made up of originally deposited areas of quartz. In some portions the layers of the gannister quarries are quite thin-bedded. In sections from some of these thin-bedded portions in the quarries on the north side of Carp River the quartz areas are all elongated in a common direction, the lengths of the areas being usually great in proportion to their widths. These elongated grains of quartz interlock and overlap one another just as do the quartzes of many mica schists and gneisses. This arrangement in the present case is perhaps partly due to the pressing into this position of originally oblong areas, but it seems also to be due in part to the elongation of the quartzes by secondary enlargements. Fig. 1, Plate VI, represents a thin section of the non-schistose portion of this rock. (Slides 1012, 1479.)

### 23. Northwest corner of Teal Lake, Michigan. (Brooks's "Formation V," "Lower Quartzite.")

A gray and brown vitreous quartzite. The same ledge shows also greenish, chloritic quartz-schists. In the sections of the non-schistose portions the induration is seen plainly to be the result of the interlocking of the enlargements of the original clastic particles, whose smoothly-rounded outlines are strongly marked. The cementing silica has, however, not all of it united with the original grains, some of it having separated out interstitially in minute interlocking areas. The peculiar appearance of gradation of a quartz area into fine interstitial quartz, due to the diminution outwards in power of the crystalline influence of the nucleal grain, is here noticed also. The more schistose portions of the rock of this ledge are seen in the thin section to carry a larger proportion of kaolin, and to have but little of the indurating silica co-ordinated with the original fragments, most of it having been deposited independently of them. (Slide 988.)

[18] Geol. Sur. of Mich., Vol. I, p. 83.



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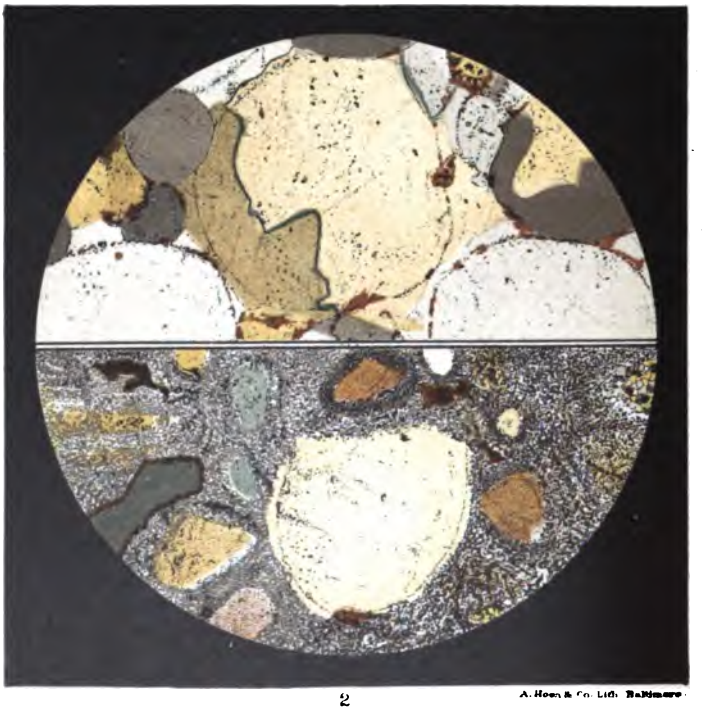

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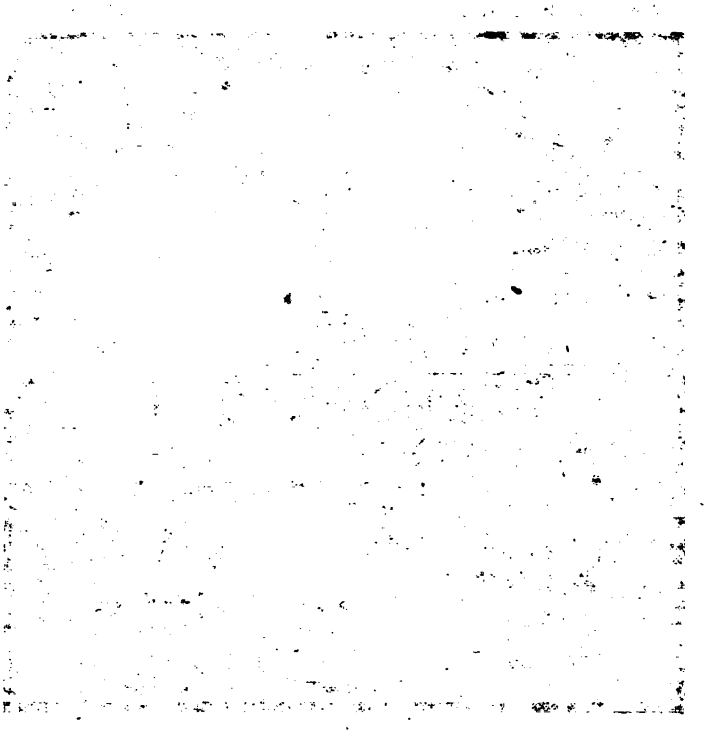
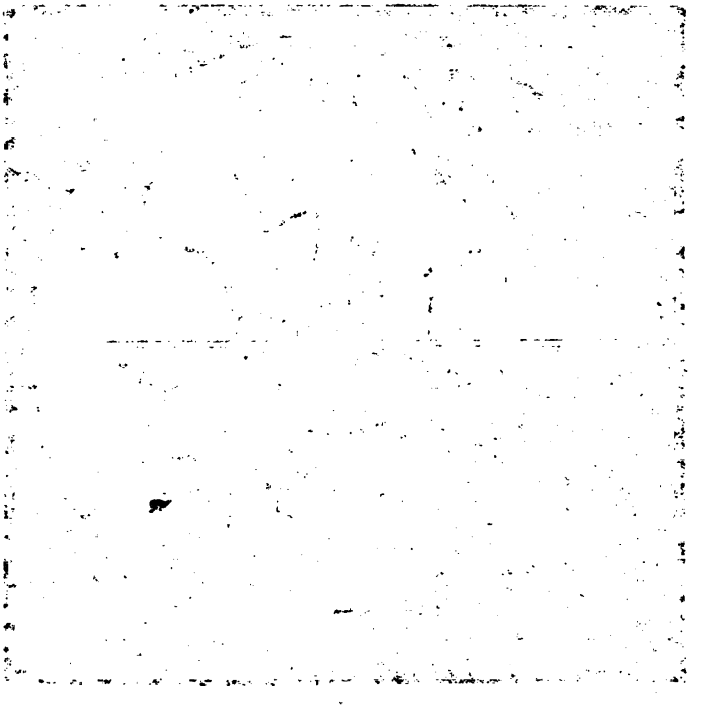
THIN SECTIONS OF QUARTZITES.





24. Hanging wall of Palmer Mine, Michigan. (Brooks's "Formation V," "Lower Quartzite.")

A dark-gray, conglomeratic quartzite. The numerous, large-sized quartz fragments of this rock, some of them simple, some of them complex, are buried in an abundant matrix, which is composed of finely-divided quartz mingled with amorphous or chalcedonic silica, the latter at times predominating, along with kaolinic material, flakes of muscovite and chlorite, and of oxide of iron. The quartz fragments are often angular, but there is no evidence that the angularity is due to secondary enlargements of rounded grains. The induration seems to be wholly due to the independently deposited interstitial silica. (Slide 973.)

25. Hanging wall, Saginaw Mine, Negaunee District, Michigan. (Brooks's "Formation XIV," "Upper Quartzite.")

A very dark-colored, conglomeratic quartzite, the pebbles partly of clear quartz and partly of red and black jaspery or cherty material. The rock is very much indurated, the induration being chiefly due to the independent deposition of interstitial quartz and of some amorphous silica, there being but few and small enlargements of the quartz fragments. Oxide of iron is very abundant in the matrix, which includes also some kaolinic material and muscovite scales. (Slide 1457.)

26. Hanging wall, Spurr Mine, Michigamme District, Michigan. (Brooks's "Formation XIV," "Upper Quartzite.")

A highly vitreous, dark-gray, conglomeratic quartzite, mostly made up of large, clear, often interlocking quartz areas, which are in many cases plainly, and inferentially always, due to the enlargement of fragments. A few biotite flakes, often altered into chlorite, as also particles of muscovite, microcline, and orthoclase, are contained. Within six feet across the strike this clear, vitreous quartzite passes into the chlorite schist, which carries the well-known chlorite pseudomorphs after garnet. There is a complete variation from one rock to the other within this distance. (Slide 1279.)

## B.—*Quartz-schists.*

27. Quartzite range, south of Marquette, near shore of Lake Superior (N. W. ¼, Sec. 1, T. 47, R. 24 W., Michigan). (Brooks's "Formation V," "Lower Quartzite.")

A red, dolomitic quartz-schist. This rock grades within a few feet into the red, non-schistose quartzite described above as No. 20, and in another direction, within an equally short distance, into a clay slate, with strong transverse cleavage. The thin section shows quartz grains imbedded in a fine matrix. The quartz grains often show strongly marked secondary enlargements. The matrix contains some little kaolinic matter and some fine quartz, but appears to be chiefly made up of a finely crystalline dolomite, which is to be regarded as of a secondary nature. The red color is due to a minute quantity of iron oxide. (Slide 1007.)

28. North of Michigamme Mine (N. W. ¼, N. W. ¼, Sec. 20, T. 48, R. 30 W., Michigan). (Brooks's "Formation V," "Lower Quartzite.")

A dark- and light-banded quartz-schist, the light-colored bands being vitreous and quartzitic, the dark-colored ones being much finer and more clay-slate-like. There is a tendency to transverse cleavage, especially in the dark-colored bands. In the thin section the light-colored bands are seen to be composed mainly of worn grains of quartz, which have often been enlarged, and sometimes so much so as to interlock quite deeply. An interstitial material is present, composed of very fine quartz, with

biotite and kaolin scales, with a little chlorite and iron oxide. In sections of the dark-colored bands this matrix material becomes predominant. (Slides 1284, 1285, 1286.)

### C.—*Mica-schists.*

**29. North of Michigamme Mine (N. W. ¼, N. W. ¼, Sec. 20, T. 48, R. 30 W. Michigan). (Brooks's "Formation V," "Lower Quartzite.")**

A very fine-grained schist, strongly marked with very thin bands of sedimentary deposition, and exhibiting an imperfect slaty cleavage. Closely resembles much of the slate exposed along the Saint Louis and Mississippi Rivers, Minnesota, and grades into the rock last described, the only difference being that here the finer material predominates. In the thin section this resemblance is borne out, and the rock is seen to be composed as the matrix of No. 28. Some of the minute quartzes have distinctly been enlarged from fragmental particles. Crystals of garnet occur very sparsely scattered through the section. It is difficult to say how much of the fine quartz of this rock is the result of crystallization *in situ*, and how far the result of the enlargement of fragments. (Slide 1289.)

### D.—*Sandstone.*

**30. Short distance north of the foot-wall of Spurr Mine, Michigamme, District, Michigan. (Brooks's "Formation XII.")**

A fine-grained, saccharoidal, very friable, white sandstone, the grains being provided with crystal faces. Certain bands, one-eighth to one-fourth of an inch wide, carry much maguetite. The sand crumbled from the rock by hand shows, in a balsam mounting, that each one of the faceted grains has a rounded fragment as a nucleus. It is only with a particular disposition of the light that the outlines of the original grains can be detected, so clear are both the nuclei and the enlargements. The crystal terminations are generally both present. See Fig. 3, Plate II. (Slides 1274, 1433, 1434.)

#### FROM THE IRON-BEARING SERIES OF THE PENOKEE REGION, WISCONSIN.

### A.—*Vitreous quartzites.*

**31. Near Penokee Gap, Ashland County, (N. W. ¼, Sec. 14, T. 44, R. 3 W., Wisconsin.) ("Formation III" of the Penokee series, "Siliceous Schist.")[19]**

A greenish, vitreous quartzite, composed almost wholly of intricately interlocking quartz areas of some size, each one of which has, however, plainly been enlarged from a fragmental nucleus. Chlorite in small particles forms the only other ingredient. (Slide 1402.)

**32. Gorge of Tyler's Fork, Ashland County (S.E. ¼, N.E. ¼, Sec. 33, T. 45, R. 1 W., Wisconsin). ("Formation III.")**

A greenish, vitreous quartzite, closely like the rock last described, except that the induration, though chiefly, is not wholly due to the enlargement of the original fragments, there being present quite a quantity of a finely divided interstitial quartz. The chlorite, besides occurring in bunches, is noticed also to occur in films around the outlines of the nucleal grains of the quartz areas. (Slide 2094, Wisconsin survey series.)

[19] For the stratigraphy of the Penokee series, and the numbers given to its subordinate members by R D. Irving, see Geol. of Wis., Vol. III, p. 104. For a description of Formation III throughout its extent, see the same, pp. 111–118.

33. Bad River, Ashland County (S.W. ¼, N.W. ¼, Sec. 11, T. 44, R. 3 W., Wisconsin). ("Formation XV."[20])

A very dark-gray feldspathic quartzite, composed of angular quartz and partly kaolinized feldspar fragments (the former often slightly enlarged) imbedded in an abundant matrix composed largely of the same materials, with a good deal of a blackish iron oxide in fine particles. As is usual where there is much of a fine fragmental or clayey matrix, the quartz fragments appear to merge into the matrix. (Slide 1496, Wis. sur. series.)

34. Near Penokee Gap (west line N.W. ¼, Sec. 11, T. 44, R. 3 W., Wisconsin). ("Formation XIX."[21])

A very fine-grained, dense, black, vitreous quartzite. Quartz in minute particles is the most abundant ingredient. Much of it appears clearly to be of a clastic origin, and the grains have often received secondary enlargements. Biotite in abundant, minute, brown scales; fragments of feldspar, pyrite, and brown iron oxide are the remaining ingredients. (Slide 1113.)

B.—*Quartz-schists.*

35. The gorge of Tyler's Fork, Ashland County (N.E. ¼, Sec. 33, T. 45, R. 1 W., Wisconsin). ("Formation III.")

A greenish-gray, vitreous quartzite, very clearly resembling No. 28 of this list. Quartz, in relatively large, interlocking areas, composes fully three-fourths of the section, each area having a distinctly marked, nucleal fragment. The enlargements of these fragments are often unusually wide, and the interlocking at times quite intricate. A little, finely-divided quartz is present in the interstices. Chlorite occurs in large rounded areas, which are taken to have resulted from the decomposition of feldspar fragments in films and patches between the quartz areas, and in films following the outlines of the original grains, thus taking the place more usually occupied by iron oxide, which is, however, also present to some extent here. (Slide 1111.)

36. South line Sec. 27, T. 45, R. 2 W., Ashland County, Wisconsin. ("Formation XXI."[22])

A light-gray, fine-grained quartz-schist. Rather sparsely scattered fragments of quartz and feldspar, the former the most abundant, are scattered through a matrix composed of the same materials, with more or less kaolin, muscovite, chlorite, and iron oxide, in fine particles. The quartz fragments are often distinctly enlarged. (Slide 1113.)

C.—*Mica-schist.*

37. West line S.W. ¼, Sec. 2, T. 44, R. 3 W., Ashland County, Wisconsin. ("Formation XXI," the great mica-schist at the top of the series.)

A light-gray, very fine-grained, quartzose mica-schist. Quartz in closely fitting areas, in many of which a nucleal fragment may be recognized, is the chief constituent. There is also some fragmental orthoclase. The mica (biotite) lies between the quartz areas, and along with it there is often some brown oxide of iron. (Slide 2006, Wis. sur. series.)

[20] Geol. Wis., Vol. III, p. 142.
[21] Geol. Wis., Vol. III, p 144.
[22] Geol. Wis., Vol. III, pp. 145–149.

### D.—*Graywacke and graywacke-slate.*

**38. Tyler's Fork (N.E. ¼, Sec. 28, T. 45, R. 1 W., Ashland County, Wisconsin). ("Formation XVII."[23])**

A very dark-gray, fine-grained rock, similar macroscopically and microscopically to No. 33 of this list, differing only in the larger proportion of the feldspathic and clayey material. Many of the quartz grains are distinctly enlarged, and present the common appearance of merging into the matrix. The decomposed feldspar fragments have about them often borders of a fresh feldspathic material, an occurrence suggesting that they too have received secondary enlargements. (Slide 2104, Wis. sur. series.)

### E.—*Arenaceous quartzite and sandstone.*

**39. Penokee Gap, Ashland County, Wisconsin, (N.E. ¼, N.W. ¼, Sec. 14, T. 44, R. 3 W., Wisconsin). ("Formation II."[24])**

A milky-white, arenaceous or semi-vitrified quartzite. Except some few minute particles of brown oxide of iron, the slide shows nothing but quartz in closely fitting, sometimes interlocking areas, within many of which may be seen the outlines of the nucleal fragments. The slide is evidently from one of the more vitrified portions, the rock being quite irregular in the degree of induration. (Slide 1110.)

**40. Mount Whittlesey, Ashland County (N.W. ¼, N.W. ¼, Sec. 16, T. 44, R. 2 W., Wisconsin). ("Formation II.")**

A very fine-grained, white, indurated sandstone, closely like the last rock described, except that the enlargements of the grains are very frequently furnished with crystal faces, as may be seen both in the thin section and in the balsam mounting of sand crumbled from the rock. This is evidently a common peculiarity of this layer in the Penokee series, since hand specimens from different localites are made up of sparkling grains. There is often a very abrupt transition from the highly arenaceous to the strongly vitrified phase. (Slides 1406, 1465, 1482.)

#### IN THE SLATES OF THE SAINT LOUIS RIVER, MINNESOTA.

**41. Knife Falls, Saint Louis River, Minnesota.**

A fine-grained, light-gray, highly argillaceous schist. Minute fragments of quartz, orthoclase, and oligoclase, the first-named often with small enlargements, are buried in a fine matrix, composed partly of the same materials and partly of kaolin, with some chlorite.

**42. Near Mahtowah, Minnesota.**

An arenaceous schist, closely resembling the last described, both macroscopically and microscopically, except that it is somewhat coarser grained. The quartz fragments are often enlarged. (Slide 766.)

**43. Saint Louis River, near Thompson, Minnesota.**

A very dark-gray, fine-grained graywacke. The thin section shows the rock to be composed much like the last two described, except in containing a larger quantity of feldspar fragments, and in having a larger proportion of chlorite in the matrix. The quartz fragments are often distinctly enlarged.

These rocks are all somewhat nearly allied to the graywacke-slates of Lake Huron. They are, however, whilst fine-grained, only the coarser phases of the great slate formation in which they occur, the predominating phases of which are true-clay slates

[23] Geol. Wis., Vol. III, p. 142.
[24] Geol. Wis., Vol. III, p. 108.

and a very fine-grained, shining mica-slate, in which the proportion of decomposed feldspar detritus is often very large, and the quartz fragments are so minute that if any secondary enlargements occur they are very difficult of detection. The whole series is affected by a very strong transverse cleavage, the fine bands of sedimentary lamination being at the same time often most beautifully preserved. (Slide 761.)

IN THE QUARTZITE FORMATION OF THE BARABOO REGION OF WISCONSIN.

### A.—*Vitreous quartzites.*

### 44. Caledonia, Columbia County, Wisconsin.

A grayish-white quartzite conglomerate, the pebbles being of white quartz and of small size. In the thin section quartz fragments of some size, often showing distinctly secondary enlargements, are buried in a finer matrix, chiefly of the same material, some of which may be fragmental, but much of which appears to be originally deposited material. (Slide 729.)

### 45. Upper Narrows of the Baraboo River, Sauk County, Wisconsin.

Dark purple, vitreous, close-granular quartzite, made up almost wholly of interlocking areas of quartz, each one of which has been produced by the enlargement of a fragmental nucleus whose outline is always strongly marked by oxide of iron. The lines along which the interlocking areas of quartz join are peculiarly jagged. There is also present some of a fine, independently deposited interstitial quartz. (Slide 745.)

### 46. Freedom, Sauk County, Wisconsin.

A pinkish white, very close-grained, vitreous, translucent quartzite. The thin section is made up entirely of irregularly outlined, interlocking, angular areas of quartz, all of which have evidently been formed by the enlargement of fragmental nuclei, the outlines of which, however, are usually very faintly marked. While plainly composed in the main of detrital material, this rock, but for the discovery that these enlargements exist in other quartzites, would undoubtedly be taken as made up entirely of quartz crystallized *in situ*. (Slide 744.)

### 47. Westfield, Sauk County, Wisconsin.

A pinkish, vitreous, translucent quartzite, composed chiefly of interlocking quartz areas, the outlines of the original fragments being generally very distinctly marked. The enlargements are usually not broad. There is a small quantity of fine interstitial quartz which appears to have been deposited *in situ*.

### B.—*Quartz-schists.*

### 48. Lower Narrows of the Baraboo River, Sauk County, Wisconsin.

A yellowish-white, granular, argillaceous quartz-schist, composed in about equal proportions of a fine clayey matrix, and of rounded fragments of quartz with some of feldspar. The matrix includes also some fine quartz. The quartz fragments show the usual small enlargements and appearance of fading into the matrix, so often noted above as characteristic of clayey quartzites. (Slide 735.)

### 49. Ableman's, Sauk County, Wisconsin.

A dark-grayish, vitreous quartz-schist, made up chiefly of enlarged quartz grains, elongated in a common direction, whence the schistose structure. There is a minor quantity of fine interstitial quartz. (Slide 748.)

### 50. Upper Narrows of the Baraboo River, Sauk County, Wisconsin.

Pink, fine-grained, quartz-schist, made up chiefly of grains of quartz, with their longer axes lying in a common direction, each enlarged from a nucleal fragment.

One-fourth of the rock is made up of a fine filling material, which is about equal parts of fine quartz and kaolin. (Slide 746.)

### C.—*Sandstone.*

### 51. Devil's Lake, Sauk County, Wisconsin.

The larger portion of the quartzite in the Devil's Lake region is without arenaceous appearance, but now and then a tendency to an arenaceous appearance is notable, and occasionally small areas are met with where the rock is only a slightly indurated or even a quite loose sandstone. The transition from friable sandstone to the most indurated quartzite is quite abrupt. The present slides consist of a balsam mounting pulverized from one of the slightly indurated portions. Each rolled grain of sand is seen to be surrounded by a secondary border of limpid quartz, on which, however, crystal faces are not to be observed, the interference having been too great. (Slides 820, 821.)

#### IN THE QUARTZITE FORMATION OF SOUTHERN MINNESOTA.

### A.—*Vitreous quartzites.*

### 52. Redstone, Nicollet County, Minnesota.

In southwestern Minnesota, and westward in Southeastern Dakota, as far as the James River Valley, are areas of a sandstone and quartzite formation, which evidently underlies all of this region, the exposures being detached from one another by the overlying Cretaceous and Quaternary formations. Unfortunately, the next newer formation with which it is seen in contact is the Cretaceous, so that stratigraphical proofs of its geological position are wanting. It is contrasted so completely with the Potsdam formation of the Mississippi Valley that there can be no question of its inferior position. So far all who have examined it of late years are agreed. Professor Winchell, if he is rightly understood by us, is disposed to regard it as the equivalent of the lower portion of the copper-bearing series. Certain of the reddish, more argillaceous, and more sandy parts of the formation are often much like some of the red sandstones of the copper series, although the similarity does not hold on closer inspection. In its quartzitic portions the formation is almost identical in character with the Huronian quartzites of the Baraboo region of Wisconsin. In its more argillaceous portions, also, it approaches very nearly the argillaceous members of the series of the Penokee region, and the pipestone-bearing quartzites of Barron County, Wisconsin. These resemblances, the evident considerable thickness of the series, and the differences between it and the Keweenawan rocks leave little doubt in our minds of the correctness of the position taken by those who would refer it to the Huronian. It may be said that much of the quartzite of this region is near to much of the quartzite of the Huronian of Lake Huron.

At Redstone the transitions from argillaceous, reddish sandstone to completely vitrified, brick-red to purple quartzite, and from these again to completely loose sandstones, are frequent and abrupt. In places, over considerable areas, the appearance is as if the rock at higher levels had been vitrified by exposure. But in the railway cutting it is seen that the vitreous quartzites are not restricted to the exposed portions, but are interstratified with, and arranged in irregular areas in, an entirely unindurated crumbling sandstone. The peculiarly irregular distribution of the induration, and the abrupt transitions from indurated to non-indurated material, suggest the possibility of its production by the descent along joints and the spreading thence through the layers of a silica-bearing solution. The thin sections of the completely vitrified quartzites of this place show the outlines of the original fragmental grains strongly marked by borders of oxide of iron. In the main the fragments are simple, but at times they are composed each of several interlocking quartz areas. All of

these fragments have been enlarged, the simple ones in the usual manner and the complex ones into larger complex areas. The enlargements at times interlock, but in other portions of the sections interstices are left between them, which have been filled by an independently deposited silica, a portion of which is chalcedonic or amorphous. (Slide 1376.)

### 53. Near New Ulm, Nicollet County, Minnesota.

A fine conglomerate, forming the matrix of a boulder conglomerate composed of white quartz pebbles, imbedded in a still finer matrix of fine quartz, kaolin, and oxide of iron. The quartz fragments were in the main originally complex, but have been slightly enlarged. (Slide 1373.)

### 54. Delton, Cottonwood County, Minnesota.

A pinkish, glassy quartzite. The thin sections show essentially the same characters as No. 52 of this list. Some of the interstitial material of these rocks is fibrous, chalcedonic silica arranged radially about some of the complex grains of quartz. (Slides 1380, 1381, 1382.)

### 55. Mound Creek, Germantown, Cottonwood County, Minnesota.

An arenaceous, gray quartzite. The thin sections resemble those of the immediately preceding numbers, except that the induration has not proceeded so far, the enlargements of the grains not having commonly interlocked. There is much of a fine quartzose matrix. (Slide 1383.)

## B.—*Sandstone.*

### 56. Redstone, Nicollet County, Minnesota.

A fine-grained, somewhat indurated, red, argillaceous sandstone. Fragments of quartz, partly simple, partly finely complex, the former often enlarged, are buried in a matrix of red iron oxide, clayey material and fine quartz. (Slide 1375.)

### 57. Redstone, Nicollet County, Minnesota.

One end of the specimen is a purple vitreous quartzite, like No. 52; the other a loose sandstone, with the grains faceted from secondary enlargement. We have, then, in this specimen the two extremes of the process of induration. (Slides 1377, 1378.)

## IN THE ANIMIKIE SERIES OF NORTHERN MINNESOTA AND THE THUNDER BAY REGION OF LAKE SUPERIOR.

## A.—*Vitreous quartzites.*

### 58. Prairie River Falls, (Sec. 34, T. 56, R. 25 W., Minnesota).

A red, vitreous quartzite, closely resembling much of the red quartzite of Southern Minnesota (*e. g.*, No. 54 of this list); also the red quartzites occurring in the Marquette (*e. g.*, No. 20) and Baraboo Huronian regions (*e. g.*, No. 47). The induration has been entirely produced by the enlargement of very much rounded fragments, whose outlines are beautifully marked in the thin section by lines of red and brown oxide of iron. The enlargements have often very intricately interlocked. Rutile needles are plentiful in the original fragments, coming up often quite to their outlines, but are altogether absent from the enlargements. There is no other mineral of importance present. The quartz fragments are usually simple, but are occasionally made up of two or more interlocking quartz areas. Figs. 1 and 2, Plate IV, magnified 39 diameters, represent portions of this rock in the ordinary and polarized lights, so that the present and original extents of the quartz areas may be readily seen. See also Fig. 2, Plate VI., upper half. (Slides 1088, 1089.)

### 59. Wauswaugoning Bay, Lake Superior, Minnesota.

A light-gray, vitreous quartzite. Angular quartz areas, each plainly enlarged from a nucleal grain, and often interlocking, make up most of the rock. There are also present fragments of feldspar and fragments made up of very minute interlocking quartz areas. Chlorite is present in the matrix, which appears to be in part composed of quartz deposited *in situ*. (Slide 413.)

### 60. Pigeon Point, Lake Superior, Minnesota.

A very dark-gray, nearly black, compact, very fine-grained, vitreous quartzite. Consists of angular quartz areas, plainly enlarged from fragmental nuclei, whose outlines are often visible, with some fragments of feldspar (both orthoclase and plagioclase), imbedded in a matrix made up of minute interlocking quartz areas, chlorite and biotite flakes and abundant small round grains of a brightly polarizing, colorless mineral, which is nearer in appearance to the sahlite variety of augite than to anything else with which we are familiar. This rock is very near to those described as vitreous graywackes, the only difference being in its greater richness in quartz, and highly vitreous character. It is also very close, indeed, to the more quartzitic phases of the "slate-conglomerates" of Lake Huron, and is quite as completely a "crystalline" rock as anything except the greenstones to be found in the type Huronian of Lake Huron. It is a type of rock which is largely concerned in the make-up of the Animikie series. It is directly interstratified with arenaceous quartzites or even sandstones. (Slide 423.)

## B.—*Arenaceous quartzites.*

### 61. Portage Bay Island, Minnesota, coast of Lake Superior.

The light-gray, fine-grained arenaceous rock of Portage Bay Island is often little more than a slightly indurated sandstone, but in places it becomes a decided quartzite, and though always somewhat more arenaceous, gives sections which resemble very closely those of No. 59 of this list, the induration being merely not quite so strong. The outlines of the original fragments are beautifully distinct, and the enlargements are very broad. There is some calcite present in the matrix. (See Fig. 2, Plate III.) (Slides 402, 403.)

## C.—*Vitreous graywackes.*

### 61. South side of Rove Lake, Minnesota (N.E. ¼, Sec. 28, T. 65, R. 1 E. Minnesota).

A fine-grained, dark-gray, much indurated rock, with conchoidal fracture. This rock differs from No. 60 in its larger content of feldspathic and chloritic material. It may be taken as the type of the rock which forms the larger part of the Animikie series. The quartz is the principal mineral and occurs in three phases: (1) in simple fragmental grains, always showing some secondary enlargements; (2) in complex fragments, which are also occasionally enlarged; (3) as an interstitial material in minute interlocking areas. The feldspar fragments include orthoclase and plagioclase, and are very plentiful, often closely interlocking with the enlarged quartzes. Some kaolinic material in the matrix probably represents decomposed feldspars. Some chlorite is also present in the matrix. The rock is fully as "crystalline" as anything in the original Huronian, to the graywacke-slates of which it is closely comparable, especially to the more quartzitic phases of those rocks. It is still closer to some of the quartzitic phases of the slate series of the Saint Louis River (*e. g.*, No. 43) and of the great series of folded schists of the Knife and Kingfisher Lake region on the national boundary. (Slides 1346, 1347.)

63. East end of Mountain Lake (S.W. ¼, S.W. ¼, Sec. 13, T. 65, R. 2 E., Minnesota.)

A lighter-colored rock than No. 62, but otherwise identical with it. (Slide 1350.)

64. Partridge Falls, Pigeon River, Minnesota.

A feldspathic quartzite or vitreous graywacke, very close to No. 62, differing only in having less interstitial material, and, consequently, more thorough interlocking of the enlarged quartz areas with each other, and with the feldspar particles. (Slides 1181, 1328.)

65. South side of Clear Water Lake (near center of Sec. 27, T. 65, R. 1 E., Minnesota.)

Differs from No. 62 only in being finer grained, being otherwise identical with it, macroscopically and microscopically. (Slide 1178.)

66. East side of Thunder Bay, Canada.

A dark-gray rock, near to No. 62, except that it is finer grained and is more argillaceous. The thin section shows a larger quantity of kaolinic interstitial material than No. 62, and a larger proportion of chlorite. The usual enlargements of the quartz fragments are found. (Slide 432.)

### D.—*Argillaceous graywacke.*

67. Grand Portage Falls, Pigeon River, Minnesota.

A fine-grained, light-greenish-gray, argillaceous, not greatly indurated rock. The thin section is near to that of No. 62, but shows a very much larger amount of a clayey matrix, and less of a siliceous cement. The quartz fragments are often enlarged. (Slide 1355.)

IN THE FOLDED SCHIST OF THE NATIONAL BOUNDARY LINE, NORTH OF LAKE SUPERIOR.

68. Kingfisher Lake (S.W. ¼, S.E. ¼, Sec. 23, T. 65, R. 6 W., Minnesota.

A dark-gray, fine-grained, vitreous graywacke or quartzite, somewhat coarser grained than No. 62 of this series, but otherwise closely like it. This resemblance holds also in the thin section, except that this rock is, perhaps, somewhat more feldspathic. The quartz fragments are often enlarged. (Slide 1147.)

69. Kingfisher Lake (N.W. ¼, N. E. ¼, Sec. 26, T. 65, R. 6 W., Minnesota.

A dark-gray, fine-grained rock, resembling the last described, but somewhat coarser-grained. Close also to much of the graywacke of the slate-conglomerate of Lake Huron. In the thin section, quartz and feldspar fragments, the former often enlarged, and the latter including both orthoclase and plagioclase, are embedded in fine matrix composed partly of quartz, but also in part of amorphous silica and kaolin, with also numerous particles of oxide of iron. Chlorite is abundant as an alteration-product of the feldspars. (Slide 1144.)

70. Knife Lake (N. W. ¼, S. E. ¼, Sec. 17, T. 65, R. 6 W., Minnesota).

A fine-grained, dark-gray cherty quartzite or quartz-schist. The fragments of quartz are oftened enlarged. Orthoclase and plagioclase compose about one-half of the rock, the remainder being made up of an excessively fine, siliceous matrix material, which, in a large measure, has no effect on the polarized light.

It is of considerable interest as bearing upon the question of the structural relation

of the rocks of the great slate series, from which these specimens come, to the Animikie series south of them, that there should be such a close lithological resemblance between the rocks of the two series.[25] (Slide 1151 )

*KEWEENAWAN SANDSTONES.*

### 71 Eagle Harbor, Keweenaw Point, Michigan.

A red sandstone from the uppermost part of the "great conglomerate." This rock, which is made up of the detritus of different acid porphyries, is described in detail in the second part of this bulletin, since the induration has been mainly due to the secondary enlargement of feldspar fragments. The few grains of quartz contained are observed at times to have received secondary enlargements. (Slides 596, 1474.)

### 72. Near Copper Falls Mine, Keweenaw Point, Michigan.

A red sandstone from a layer interstratified with amygdaloids and traps, much resembling No. 71, except that the principal indurating material is calcite. The occasional quartz grains show very distinct enlargements.[26] (Slide 526.)

### 73. North side Portage Lake (Nonesuch Belt[27]), Keweenaw Point, Michigan.

A fine-grained, dark-colored, strongly-indurated sandstone, composed in large part of the detritus of the acid porphyries and basic rocks of the Keweenaw series, but containing also a large proportion of quartz fragments, most of which show distinct secondary enlargements.[28] (Slide 614.)

### 74. Foot-wall of the Nonesuch Mine, Porcupine Mountains, Michigan.

A light-reddish brown, streaked, fine-grained sandstone, composed about two-thirds of fragments of basic and acid eruptives, the remainder being quartz fragments, many of which are quite angular, and seemed to have broken from the crystals of a quartz-porphyry. In many cases these fragments have received secondary enlargements.[29] (Slide 617.)

### 75. Little Iron River, (N. W. ¼, N. W. ¼, Sec. 12, T. 50, R. 43 W., Michigan).

A fine-grained, dark-gray, much indurated sandstone or graywacke, the silver-bearing rock of Iron River. The predominant quartz occurs in the two forms of interlocking areas of some size, each with a plainly fragmental nucleus, and of an independently deposited interstitial material. The quartz fragments are at times finely complex. The remainder of the rock is made up of quartz-porphyry detritus, with some infiltrated calcite. (Slide 620.)

### 76. Little Iron River, (S. W. ¼, Sec. 13, T. 51, R. 42 W., Michigan).

A rock close to the last described and coming from the same "silver belt," differing chiefly in having more infiltrated calcite in the matrix. The induration is, however, largely due to infiltrated quartz, which occurs both as enlargements to the quartz fragments and independently oriented.

The rocks from the same belt on Big Iron River, on the lake shore near Lone Rock,

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[25] Monographs of the U. S. Geological Survey, Vol. V. pp. 399, 417.

[26] For description and figure of this rock, see monograph on Copper-Bearing rocks of Lake Superior, p. 129, and Plate XVI, Fig. 3.

[27] *Op. cit.*, pp. 193, 220–224.

[28] For further description of this rock, see *Loc. cit.*, p. 131.

[29] *Op. cit.*, p. 131.

and in the vicinity of Presqu' Isle River, except that the basic detritus and infiltrated calcite become more abundant, present the same appearance. (Slide 655.)

77. Presqu' Isle River, (NE. ¼, sec. 5, T. 49, R. 45 W., Michigan). Upper sandstones of the Keweenaw series.

A dark-red, fine-grained sandstone, closely similar to the last two described. The quartz fragments are both simple and complex, the first often widely enlarged. (Slide 355.)

78. Silver Islet Landing, north shore of Lake Superior, Canada.

A fine-grained, cream-colored, indurated sandstone. Angular, often interlocking quartz areas, each with a fragmental nucleus plainly outlined, make up most of the rock. Independently deposited quartz and some dolomite occur interstitially.[30] (Slides 471, 472.)

79. East side of Black Bay, Lake Superior, Canada.

A fine-grained, red-and-white-streaked, quite indurated sandstone. Subangular fragments of quartz, often showing quite wide and distinct enlargements, along with feldspar fragments, are buried in a matrix of finer fragmental quartz, which, in the red bands, is mingled with red oxide of iron and, in the white ones, with dolomite. (Slide 477.)

80. Burnt Island, Nipigon Bay, Lake Superior.

A fine-grained, brick-red, very much indurated sandstone, almost a quartzite. The predominating quartz is in interlocking areas each with a distinctly outlined fragmental nucleus— he enlargements having at times been very wide—and also in the shape of an independently deposited finely divided material. The feldspar fragments are plenty, and the rock is stained with oxide of iron. (Slide 491.)

*CAMBRIAN ROCKS.*

IN THE GRAND CAÑON GROUP OF THE COLORADO RIVER.

81. The Grand Cañon of the Colorado, near the mouth of the Little Colorado River, Arizona.

The specimens from this locality, kindly furnished us by Mr. Walcott, of the U. S. Geological Survey, range from a moderately indurated sandstone to nearly wholly vitreous quartzite. They are nearly white in color, and consist almost wholly of quartz with a minute quantity of iron oxide. The outlines of the original fragments are everywhere distinct, but always lie some distance within the individual areas, which interlock more or less thoroughly. (Slides 1363–1366 inclusive.)

IN THE POTSDAM SANDSTONE OF THE MISSISSIPPI VALLEY.

82. Immediately above unconformable contact with Huronian iron ores, Cyclops and Norway mines, Menominee iron region, Michigan.

A very much indurated, buff to brown sandstone—at times almost a vitreous quartzite. The thin section is composed, almost entirely, of interlocking grains of quartz, each with its distinctly outlined fragmental core. There is a little independently deposited interstitial quartz, and a little fragmental feldspar. The rock is in no respect different from much that is to be seen among the quartzites of the Huronian. (Slides 959, 960.)

[30] For description of this rock see *Op. cit.*, p. 133.

### 83. Lower Narrows of Baraboo River, from near contact with Archæan quartzite.

A much indurated, fine-grained sandstone carrying quartzite pebbles. The quartz fragments, originally but little rounded, are all strongly enlarged, so that there is a considerable degree of interlocking. There is also present some fine independently deposited interstitial quartz. The section does not differ materially from those of many Archæan quartzites. (Slide 742.)

### 84. Roche Écrit, Adams County, Wisconsin.

A dark-purplish, in places very much indurated sandstone. The grains are all enlarged, and occasionally have crystal faces developed. (Slide 749.)

### 85. Packwaukee, Marquette County, Wisconsin.

A pale, buff-colored, much indurated sandstone, showing only very rare crystalline facets. In the thin section the grains are seen to have been enlarged slightly, so as to fit closely without any dovetailing. Occasionally the enlargements have had an opportunity to develop crystal faces. (Slides 731, 732.)

### 86. Black River Falls, Jackson County, Wisconsin.

A white, rather coarse-grained rock, not so much indurated as the last-described, and showing more crystal facets, although not very plentifully. The thin section is much like that of the rock last described, except that the enlargements are proportionally broader and have more often developed crystal faces. (Slides 733, 734.)

### 87. New Lisbon, Wisconsin.

A fine-grained, pink-and-white-mottled sandstone, from which the light is reflected in numerous sparkling points. The induration, while distinct, is only slight, small fragments crumbling readily in the fingers. The crumbled sand mounted in balsam shows every grain enlarged, the lines of junction between the old and new quartz being always strongly marked. The enlargements have in all cases developed crystalline faces, which are, however, only perfect and uninterrupted upon the smallest of the grains. In most cases they are more or less indented by the enlargements of contiguous grains. This rock may be taken as a type of the crystal-faceted sandstones. (Slides 710 to 716 inclusive.) (See Figs. 4, 5, 6, Plate II.)

### 88. Middleton, Dane County, Wisconsin.

A fine-grained, loose, white sandstone, showing the grains sparkling from crystal facets. The balsam mounting of the sand crumbled from the rock shows the grains with the usual cores and crystal outlines. (Slides 1469, 1470.)

#### IN THE EASTERN SANDSTONE OF LAKE SUPERIOR.

### 89. West Branch of the Ontonagon River (Sec. 13, T. 46, R. 41 W., Michigan).

A reddish, coarse-grained, indurated sandstone. The quartz fragments which make up the rock have all been enlarged, sometimes very much so, so as to interlock. There is also some independently oriented fine interstitial quartz. Some much reddened, feldspathic detritus is included. (Slides 95, 96, 97.)

### 90. Quarry on Torch Lake Railroad, Keweenaw Point, Michigan.

A white to pinkish, feebly indurated quartzose sandstone. Some of the less indurated portions show numbers of faceted grains. The slide here described is from one of these less indurated portions. It is seen to be made up almost entirely of much rolled quartz fragments, which have in nearly every instance been enlarged, the enlargements only occasionally showing crystalline outlines. These crystal outlines

are, however, more frequently to be seen in the balsam mounting of crumbled sand. They are not nearly so numerous, however, as in some of the rocks previously described, the grains having interfered too much to form crystal outlines. The outlines of the original grains are usually very strongly marked by brownish iron oxide. There are occasional rounded fragments of feldspar present, and in each thin section may be seen a few particles worn from some of the fine-grained Keweenawan eruptives. (See Figs. 7, 8, 9, Plate II.) (Slides 513, 514, 1471, 1472, 1473.)

See with regard to this rock also Copper-Bearing rocks of Lake Superior, pp. 356–358. See also for an earlier description M. E. Wadsworth in Bull. Mus. Comp. Zool., Vol. VII, No. 1, p. 117. Wadsworth found the crystal-outlined grains abundantly in his sections, although we failed to do so in ours until recently. He regarded these crystal grains as being the usual dihexahedral crystals of quartz-porphyries, on which view the crystals antedate the formation of the sandstone instead of being subsequent to it. More recently (Science, Vol. II, No. 23, p. 52, July 13, 1883) he has reasserted this view. But a careful re-examination of this rock, as also of others from other places within the area of the Lake Superior sandstone, has served to convince us that in all of these cases, as in all sandstones yet examined by us, provided with such faceted grains, they owe their crystal faces to secondary enlargements of rolled fragments. It is of course possible and even probable that these quartz fragments were once, some of them, the quartzes of quartz porphyries, but if so they have rarely, if ever, retained their crystal faces, as it is, indeed, hardly conceivable that they should do.

## 91. Quarries at Marquette, Mich.

A reddish, fine-grained sandstone, showing numerous minute glistening flakes of mica. Quartz fragments make up rather more than half of the rock, many of the grains being finely complex. The simple quartz grains are mostly very angular; many of them show very distinct enlargements. The remainder of the rock is composed chiefly of fragments of feldspar, including othoclase and plagioclase, with chlorite, brown iron oxide, and muscovite flakes, the chlorite having resulted from the alteration of the feldspars. The plagioclase includes quite a number of large-sized pieces of microcline.

## 92. Near Rockland. South of the Trap Range (S. E. ¼, Sec. 7, T. 50, R. 39 W., Michigan).

A fine-grained, feebly indurated, pinkish, quartzose sandstone, sparkling from presence of crystal facets, each quartz fragment being enlarged, the enlargements being often provided with crystalline outlines. (Slides 1475, 1476.)

### IN THE WESTERN SANDSTONE OF LAKE SUPERIOR.

## 93. Basswood Island, Ashland County, Wisconsin.

A fine-grained, feebly indurated, white sandstone, containing besides the quartz many feldspar fragments. The quartzes are often enlarged, the enlargements being in many cases supplied with crystal facets. (Slide 53, Wis. sur. series.)

### *SILURIAN ROCKS.*

### IN THE SAINT PETER'S SANDSTONE OF WISCONSIN.

## 94. Near Lancaster, Grant County, Wisconsin.

This rock is represented in our list only by slides kindly furnished by the Rev. A. A. Young, of New Lisbon, Wis. They are dry mountings of the sand crumbled by hand from the rock. The grains are furnished with crystal facets from secondary deposition.[31] (Slides 707 to 711.)

[31] Amer. Jour Sci., July, 1883.

## 95. Arlington Prairie, Columbia County, Wisconsin.

The Arlington Prairie is part of a large elevated area underlain by the Lower Magnesian Limestone, but dotting it here and there are small outliers of the Saint Peter's sandstone. A group of these outliers occurs in the southwestern part of the town of Arlington.[30] Most of the rock of these outliers is quite loose, and of the ordinary character of the Saint Peter's sandstone. Along its weathered surface, however, and along the sides of joint cracks, it is very much indurated, becoming even a completely vitreous quartzite for the distance of one-fourth or one-half an inch inwards from the surface. Sections of this completely vitrified portion show the quartz fragments with enlargements that everywhere fit closely together or interlock, but sections taken from an inch or two below this crust show the enlargements frequently furnished with crystal facets, the enlargements having interfered with one another sufficiently to give a slight induration. Fig. 1, Plate III, shows the appearance of a thin section of this less indurated portion as seen in the ordinary light.[31] (Slide 724).

## 96. Gibraltar Bluff, Columbia County, Wisconsin.

A very much indurated, fine-grained rock, in which a fine arenaceous texture is visible only upon the closest inspection. The rock is one which, if found among the crystalline schists, would undoubtedly be classed as a true quartzite; and the appearance of the thin section would entirely bear out this classification. It is made up only of interlocking grains of quartz of two very different sizes, the larger ones predominating. The large ones of these areas, and many of the smaller ones, show each a more or less plainly outlined fragmental nucleus. The areas interlock, often very intricately, and in every possible sense the rock is fully as "metamorphic" as any quartzite yet studied from the Archæan formations, and yet it is a mere local phase wholly independent of any igneous or other apparent metamorphosing action, in a formation whose ordinary character is that of an incoherent sandstone. In no Archæan quartzite that we have examined is the interlocking of the quarts areas, and the consequent appearance of complete original crystallization, more marked than in this sandstone.[34] See Fig. 1, Pl. V. (Slide 727.)

### IN THE EUREKA QUARTZITE OF NEVADA.

## 97. Eureka, Nevada.

This rock and the three following are the ones in which Hague and Iddings noted enlargements of quartz grains as long ago as the summer of 1881. They will be found fully described in Hague's monograph upon the Eureka district. Mr. Hague has been kind enough to furnish us specimens and slides for the purpose of comparing them with quartzites which we had examined. The specimen of Eureka quartzite furnished by Mr. Hague would be classed by us as a semi-vitreous quartzite. The enlargements of the quartz fragments of which the rock is composed has produced close fitting but never any considerable interlocking. But still the rock is fully as much altered as any of the true Huronian quartzites.

### *DEVONIAN.*

## 98. Sandstone from the White Pine shale, Eureka, Nevada.

A fine-grained, strongly indurated sandstone, composed of fragments of quarts and of chalcedonic or amorphous silica. The quartz fragments are often enlarged and are sometimes furnished with crystal faces. (Slide 1436.)

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[30] Geol. of Wis., vol. II, p. 583.

[31] For figures drawn from the vitrified crust of this rock see Amer. Jour. Sci., June, 1883, p. 407.

[34] Amer. Jour. Sci., June, 1883, p. 408.

*CARBONIFEROUS.*

**99. Eureka, Nevada, Diamond Peak quartzite.**

A fine-grained, greenish-drab, feldspathic quartzite. In the thin section feldspar, often much altered, is seen to compose a large proportion of the rock. The minute grains of quartz show relatively wide enlargements. (Slide 1368.)

*TRIASSIC.*

**100. Henry Mountains, Utah.**

A light-gray to pinkish, fine-grained, feebly indurated sandstone from near contact with one of the laccolites. Small rounded grains of quartz compose the larger part of the rock. These have often been enlarged, and the enlargements fit somewhat closely. There are some grains of feldspar and, interstitially, calcite, fine quartz, clayey material, and iron oxide. (Slide 1367.)

*CRETACEOUS.*

**101. Courtlandt, Nicollet County, Minnesota.**

A light-gray, compact, calcareous sandstone, consisting of quartz fragments embedded in a matrix of crystalline calcite. The quartz fragments, only rarely in contact with each other, have quite often been enlarged. (Slide 1384.)

## II.

## ENLARGEMENTS OF FELDSPAR FRAGMENTS IN CERTAIN KEWEENAWAN SANDSTONES.

By C. R. Van Hise.

For some time past I have been on the outlook for evidence of the secondary enlargement of feldspar fragments. In the slate conglomerates of the north shore of Lake Huron (as mentioned in Part I of this bulletin) I have found what may be enlarged feldspar grains, but the evidence is not sufficiently satisfactory that any of the material is of secondary origin, the lines of separation between the supposed new material and the nuclei being illy marked. However, I have found what seem to be additions to grains of that mineral in certain of the Keweenawan feldspathic sandstones. The specimens in which the supposed enlargements were first found are taken from those portions of the sandstones almost in contact with overlying basic eruptives. This position is evidently a favorable one for the development of such enlargements, the heated alkaline waters which would naturally descend supplying appropriate conditions. Then, too, quartz enlargements, when most easily found, are shown by lines of ferrite about the nuclei, and are ordinarily best seen in the less indurated quartzites. The Keweenawan sandstones are highly ferruginous, and are of an open texture; hence, if in them the feldspar fragments have taken new growths, the conditions for their detection are favorable.

The feldspathic sandstone immediately underlying the diabase of Eagle Harbor, Michigan, is of a uniform medium grain, a magnifying glass showing but little quartz. The feldspar grains are stained red with iron oxide. Hydrochloric acid gives with the powder a slight effervescence. In the thin section the sandstone is seen to be composed largely of grains of different feldspars, next to which in abundance are rounded complex fragments derived from a granitic porphyry,[1] consisting of feldspars penetrated by a saturating quartz. Then follow in order of abundance complex fragments of some altered basic rocks. Finally, a few grains of quartz and a little secondary calcite are noted.

The feldspars are frequently somewhat kaolinized, but most of the grains are fresh enough to give quite uniform colors in polarized light, and, in the cases of the plagioclases, well defined twinning bands. The grains are all rounded, their boundaries being broad lines of ferrite. However, some subsequent mineral has used these grains as nuclei

[1] Third Annual Report U. S. Geol. Survey, p. 114.

about which to deposit, and now each individual appears in the polarized light to extend beyond its original limits. The newly formed borders as compared to the interiors are different, in that they show no decomposition and are freer from iron stains. When the borders from different feldspathic grains have extended so far as to come in contact, as they usually have done, they form sharply serrate, nicely fitting junctions, roughly comparable to the suture of a skull (Fig. 1).

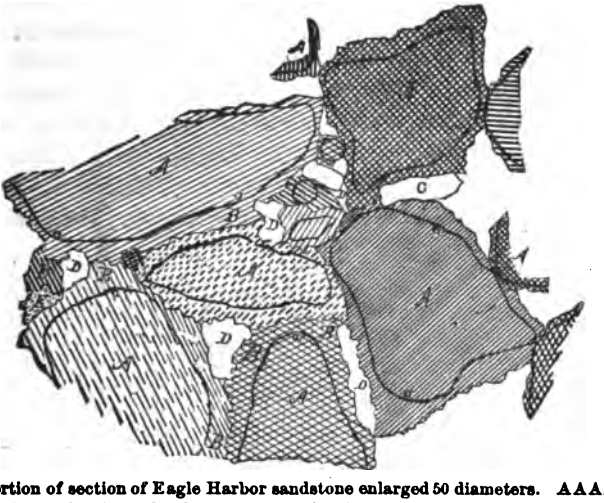

Fig. 1.—Portion of section of Eagle Harbor sandstone enlarged 50 diameters. AAA, feldspar fragments, bounded by oxide of iron borders, *aaa*, outside of which are enlargements, BBB, of the grains polarizing in each case with the nucleal fragment as indicated by the shading. C is a quartz fragment, D unfilled spaces, and E supposed secondary feldspars polarizing independently of the original fragments.

This newly added material appears to be feldspar, which has co-ordinated crystallographically with the grains about which it has deposited. It possesses no optical properties which would exclude that mineral, but cleavage and decomposition being absent, no comparison with feldspars can be made as to those characteristic features. The belief that the new material is feldspar is, however, based upon the following facts:

When the enlarged feldspar is orthoclase, the deposited substance polarizes uniformly with the nucleus about which it is seen (Fig. 1) ex-

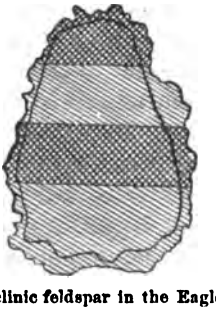

Fig. 2.—Enlarged fragment of triclinic feldspar in the Eagle Harbor sandstone, shaded so as to show how the fragment and enlargement polarize together. The black line is the heavy oxide of iron border of the original fragment.

actly as quartz enlargements polarize with the grains on which they have grown. Further, when plagioclase fragments present the enlargements, as they frequently do, the new material is twinned uniformly with the old, the twinning bands in polarized light running directly across cores and borders (Fig. 2). This phenomenon was observed in many different grains and in different sections.

Again, the complex fragments above mentioned as derived from a granitic porphyry, containing quartz and feldspar, often have enlargements, and the added portions resemble and usually polarize with the feldspars instead of with the quartz, with which they would naturally co-ordinate, if with either, were they composed of silica. Frequently the enlargements of this class of grains are apparently all of feldspar, even when a half or more of the edges of the original fragments (and in some places for considerable spaces continuously) are quartz (Fig. 3).

Fig. 3.—Enlarged fragment of feldspar, including some quartz, from the Eagle Harbor sandstone. The shading shows the feldspar fragment polarizing with the nucleus, even where not in contact with it. The black line is the oxide of iron border of the original fragment.

Finally, the complex basic fragments also have enlargements. These basic grains are often very feldspathic, the feldspar individuals being, however, small. Here a border, instead of being a unit, as it commonly is in the preceding cases, consists of several, or many individuals. The feldspars at the edge of the nucleus appear to have controlled the new growth, so that the new material polarizes with them in separate parts. These parts have, however, often extended upon each side beyond the immediately adjacent feldspars of the nucleus, and thus at times overlapped other feldspars whose conditions were less favorable for renewed growth, or other minerals, if such chance to be in contact with the division line between the fragment and its border.

The change which has taken place in one grain of orthoclase is of some interest. The grain has been broken into two parts, which have spread somewhat, and is now cemented with a new material which extinguishes with the original fragments, and also with the exterior second growth with which it is continuous in one place (Fig. 4.)

In some cases the new material deposited on a grain, instead of continuing as a single individual until it meets a similar growth from an-

other grain, has crystallized independently in small interlocking grains (Fig. 1). This independent feldspar (if I am correct in so considering

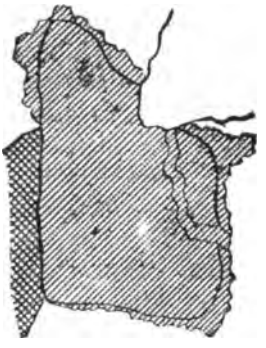

Fig. 4.—An enlarged fragment of orthoclase from the Eagle Harbor sandstone. This fragment has been broken across and cemented by a material that polarizes with the original fragment and the enlargement. The black line is the oxide of iron border of the original fragment.

it) is more plentiful about the basic fragments than about the feldspar grains or those of the granitic porphyry.

Uncovered thin sections were examined with acid, and the supposed feldspar enlargements found not to be affected. An attempt to test for hardness was not very successful. Micro-chemical tests from the nature of the case could hardly be applied.

This same secondary material has been found in other localities in the Keweenaw series, and in two cases the sandstone directly underlies eruptive greenstone.

## III.

## SUMMARY OF GENERAL CONCLUSIONS.

By R. D. IRVING.

*Genesis of Huronian quartzites.*—All the true quartzites of the Huronian are merely sandstones which have received various degrees of induration by the interstitial deposition of a siliceous cement, which has generally taken the form of enlargements of the original quartz particles, less commonly of minute independently oriented areas, and still less commonly of chalcedonic or amorphous silica; two, or even all, of the three forms occurring at times in the same rock. There may have been in some cases some solution and redeposition of the original quartz material, but in the main these rocks are still made up of the fragmental constituents that composed them before induration, the fragments retaining for the most part their original contours. That these quartzites are but altered sandstones is, of course, a truth which has long been generally recognized; it is the nature of the alteration that has not been understood.

It should be said that the term "Huronian" is here used, provisionally at least, to cover (1) the original Huronian on the north shore of Lake Huron, east of Sault Sainte Marie; (2) the iron-bearing formation of the Marquette and Menominee regions of Michigan and Wisconsin; (3) the slaty rocks of the Wisconsin Valley in the vicinity of Wausau; (4) the iron-bearing rocks of the Penokee-Agogebic range of Northern Wisconsin and Northwestern Michigan; (5) the cleaved slates of the Saint Louis and Mississippi Rivers in Minnesota; (6) the quartzites of the Chippewa River region of Western Wisconsin; (7) the iron-bearing schists of Black River, Wisconsin; (8) the quartzites of the Baraboo region, Southern Wisconsin; (9) the red quartzites and sandstones of Southwestern Minnesota and Southeastern Dakota; (10) the Animikie series of the Thunder Bay region, on the north shore of Lake Superior, and thence southwestward to Pokegama Falls, on the Mississippi River; and (11) some, at least, of the folded schists of the national boundary line.

*Huronian quartzites no more "metamorphic" than numerous sandstones of later formation.*—Without perhaps being definitely so stated, the generally accepted view with regard to the production of quartzites from

sandstones has included the idea of a more or less thorough molecular rearrangement and recrystallization of the original fragmental material, quartzites having generally been classed as metamorphic or often even as crystalline rocks. But, so far as the Archæan quartzites of the Northwest are concerned, it appears that they have undergone no other alteration than that found to affect sandstones in the later and unaltered formations in all periods down to the Cretaceous. Irregular areas, and at times mere surface films[35] in the otherwise unaltered horizontal Potsdam and Saint Peter's sandstone in the Mississippi Valley have been changed to vitreous quartzites, indistinguishable microscopically and macroscopically from the quartzites of the Archæan, while great beds of as completely indurated quartzite as any of the Huronian are met with in the unaltered Paleozoic formations of the West. These later quartzites are plainly due to the interstitial percolation of silica-bearing waters, and to the same cause must be attributed the induration of the Huronian quartzites. In the case of the quartzites of the indurated portions of the Potsdam and Saint Peter's sandstones, no possible connection with any igneous action can be conceived, the surface crusts being due to a mere weathering, the interstitial silica-bearing waters having been drawn to the surface by evaporation and capillary action. These crusts are particularly interesting, because they are evidently in process of formation at the present time, occurring wherever the accidents of denudation have produced exposed surfaces of the rock, and one cannot conceive that either heat or pressure is concerned in their production, and yet they are as completely vitreous and crystalline as any of the true quartzites of the Huronian.

In the case of the quartzites of the Huronian and other formations where there is much interstratified eruptive material, the latter may have been the source of heated silica-bearing solutions, but I can see no reason to believe that there has been any other causal relation between igneous action and the induration of the sandstones than this.

It is of interest to note in this connection that since the quartzites of the various Huronian areas, and indeed the larger part of the other non-eruptive Huronian rocks, are in no sense more altered than any fossil-bearing quartzites, etc., of later formations, it may be taken as quite certain that the failure thus far to find fossils in the Huronian is not to be attributed to their destruction by metamorphic action, but rather to an actual, original barrenness of the series.

*Other rocks in the Huronian than true quartzites have been affected by a siliceous induration.*—It also appears that, besides the true quartzites, other rocks of the Huronian—for instance the graywackes—in which quartz is merely a subordinate, or at least not the principal, ingredient

[35] See Hawes's Lithology of New Hampshire, p. 239; Dana's Geology, p. 70; Geikie's Geology, p. 117, 127; Hawes noticed the complex character of some of the quartz fragments of certain New Hampshire quartzites, and took it to mean that these grains had been recrystallized rather than that they were originally complex.

have been affected by the same sort of siliceous induration, the indurating silica occurring both as enlargements of the quartz fragments and independently of them. Accompanying this induration there has been at times a replacement of feldspathic material by quartz, and the alteration of feldspar to chlorite, the chlorite occurring both as a pseudomorphic substitute for the feldspars, and independently crystallized in the interstices. Probably, also, the feldspar fragments have received secondary enlargements analogous to those described by Mr. Van Hise in Part II of this paper. By one or more of these processes rocks have been changed so as to present macroscopically and microscopically the appearance of more or less complete original crystallization, and yet they are made up almost entirely of the original fragmental material, the alteration which they have undergone having been merely metasomatic, and not "metamorphic" as the term is generally understood.

Besides the graywackes some at least of the mica-schists of the Huronian are mainly made up of the original fragmental material, unaltered, in some cases mingled with mica that appears to have developed *in situ*, the quartz grains often showing enlargements.

"*Metamorphism*" *in the Huronian generally.*—In the various Huronian areas above enumerated, one or more of quartzites, graywackes, and clay slates, with intermediate phases, make up most of the series, from which it follows that the bulk of the Huronian is made up of rocks not properly falling under the term metamorphic.[36] I may say, indeed,

[36] I am aware that the Huronian has often been spoken of as characterized mainly by other rocks than quartzites. In "Azoic Rocks" (Sec. Geol. Sur. Penn., p. 70.), Hunt speaks of Murray's first exploration of the north shore of Lake Huron as showing the existence there of "a great series of chloritic slates and conglomerates with interstratified greenstones, quartzites, and limestones." Murray's own words (Report Geol. Sur. Canada, 1847–1848, p. 109) are, "A set of regularly stratified masses, consisting of quartz rocks, or altered sandstones, conglomerates, slates, and limestones, interstratified with beds of greenstone." "Under the denomination of slates are included various thinly laminated dark green, blackish, and reddish rocks, some of which are very chloritic and some contain epidote." In Logan's description of the series (Geol. of Canada 1863, p. 55, and atlas to the same, Plate III) the Huronian section between the Mississaugi and Saint Mary's Rivers is made to include 10,820 feet of quartzites, 4,280 feet of slate conglomerates, 2,000 feet of "chloritic and epidotic slates and trap-like beds," and 900 feet of limestone and chert. Of the "slate-conglomerates" a large proportion is quartzite, the balance being the graywacke, graywacke-slates, and graywacke-conglomerates of the first part of this paper. It should be said that the various intercalated greenstone layers of the series are included by Logan in these measurements. Having carefully examined the ground myself, I am convinced of the general correctness of Logan's section. At least two-thirds of the series is made up of quartzite. Of the balance the graywackes of the slate-conglomerate make up at least one-half. Of the remaining sixth, one-third is limestone and chert and the balance "chloritic and epidotic slates, and trap." But these chloritic and epidotic slates, which, although so insignificant a portion of the series, have been made to serve as its most prominent characteristic, are, as I have convinced myself by examining them in their typical development east of Thessalon Point and in the thin sections, merely eruptive, diabasic greenstones in various degrees of alteration. It is possible that the occurrence of the greenish chloritic graywackes in the slate-conglomerates has

although the matter cannot be discussed in this place, that as my studies progress, rocks in the Huronian, to which the term "metamorphic"—meaning that they are altered from fragmental sediments, but now consist chiefly or wholly of material crystallized in situ—would properly apply, grow fewer and fewer, those that remain being restricted almost entirely to regions where the series is highly folded.

*Mineral enlargements in rock alteration generally.*—The wide-spread importance of the enlargement of quartz fragments in the production of quartzites and other quartz-bearing indurated rocks being proved, naturally the lithologist is led to query as to whether fragments of other minerals, each after its kind, may not have received secondary enlargements, and, if so, how far such enlargements may have been concerned in the production of "metamorphic rocks." As a partial answer to this query we can offer the enlarged feldspar fragments of certain Keweenawan sandstones, described in Part II of this bulletin, and the apparent enlargements of feldspar fragments in certain of the feldspathic graywackes of Lake Huron. Further than this we have as yet nothing to offer. Certainly the field is one deserving of investigation. We have not studied any gneisses or similar rocks since our attention was drawn to this matter. Theoretically, one can easily see how such enlargements might be of great importance in the production of the crystalline schists, the enlargements being accompanied, perhaps, by partial solution of the fragmental material, and by processes of replacement and pseudomorphism, and by some recrystallization, pressure coming in to produce the foliation. As noted before, Bonney has already suggested the importance of this matter of enlargement of mineral fragments. His words are worth quoting here in full. Speaking of certain banded crystalline schists of the Lizard district, Cornwall, England, he says:

"It seems, then, possible to me that in these and in some of the curiously-banded rocks in the upper groups, many of the constituents may be in part original. I do not mean that any one grain, as it now stands, is an original constituent; crystallization *in situ*, especially in the case of hornblende and mica, has taken place to a large extent. In the more minutely crystalline schist, the original structure is very probably wholly obliterated. Still, these large feldspar grains, for instance, may have as their nucleus feldspar grains which were original constituents, and may have survived the dissolution of the finer sedimentary materials in which they were imbedded. Then, in the process of reconstitution, feldspar (not perhaps always of the same species) may have been added to feldspar, quartz to quartz, mica to mica, and hornblende to hornblende or altered augite. This traces of the minuter structure of

contributed to the idea that chloritic and epidotic crystalline rocks are its main characteristics. The type Huronian, then, *i. e.*, that of the area between the Mississaugi and Saint Mary's Rivers, should be described as a great quartzite series, including subordinate quantities of graywacke, limestone, chert, and eruptive greenstones.

the original rock, even in a highly metamorphosed series, may now and then remain. In those beds where the chemical composition of the constituents facilitated change, or where the materials were finely levigated, the agents of metamorphism reduced the whole to a mere pulp (if the expression be permissible) from which the present mineral constituents crystallized, almost as they would do from the magma of an igneous rock; but in other cases, only a portion of the material was reduced to this condition, and those constituents which remained undigested would form nuclei around which the other minerals would crystallize, and would so continue to bear testimony to the original history of the rock itself. Thus the explanation of those granitoid bands, in some cases so curiously like granite veins, may be that originally they were a rather coarse quartz-feldspar grit. As regards some of the hornblende schists, one would suggest the possibility (as I believe has been elsewhere done by the late Professor Jukes) of their having been basaltic tuffs, with which in chemical composition they would agree fairly well.

"I have ventured on this digression because these Cornish rocks have presented structures which seem to me worthy of careful consideration by all who are studying the phenomena of metamorphism—a subject which has occupied my attention for some years past. The observations are not entirely novel. Dr. Sorby drew attention to somewhat similar structures in his very valuable and suggestive paper on the original constitution and subsequent alteration of mica-schist. The agglutination of identical mineral matter has been noticed in the case of quartz by that author, by Mr. J. A. Phillips, and by myself independently, not to mention others. In the gneissic series traversed by the upper part of the St. Gothard Pass, and in other districts, I have repeatedly noticed similar instances, all tending to show that the minute structures, and in some cases very probably the original constituents (at any rate as nuclei), may be preserved in rocks which are metamorphic in the fullest sense of the word.

"I trust some day to treat the subject more fully; but I take this opportunity of calling attention to it, because I believe that in it we find a clue which may ultimately enable us to solve many difficulties in that most perplexing inquiry—the relation of the metamphoric and of the igneous rocks."[37]

[37] (Quarterly Journal Geol. Soc. Lond., xxxix, p. 19.)

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# ADVERTISEMENT.

(Bulletin No. 9.)

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The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classifications of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization. And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That, whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' [1,900] of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive Departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Williams's Mineral Resources, the Survey has no copies of any of its publications for gratuitous distribution.

## ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl., 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp.. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

## MONOGRAPHS.

So far as already determined upon, the list of the Monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. Published.

IV. Comstock Mining and Miners, by Eliot Lord. Published.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. Published.

VI. Older Mesozoic Flora of Virginia, by Prof. William M. Fontaine. Published.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. Published.

VIII. Paleontology of the Eureka District, Nevada, by Charles D. Walcott. In press.

IX. Brachiopoda and Lamellibranchiata of the Green Marls and Clays of New Jersey, by R. P. Whitfield.

## ADVERTISEMENT.

*Geology and Mining Industry of Leadville*, with atlas, by S. F. Emmons. In preparation.
*Geology of the Eureka Mining District, Nevada*, with atlas, by Arnold Hague. In preparation.
*Lake Bonneville*, by G. K. Gilbert. In preparation.
*Dinocerata*: A monograph on an extinct order of Ungulates, by Prof. O. C. Marsh. In preparation.
*Sauropoda*, by Prof. O. C. Marsh. In preparation.
*Stegosauria*, by Prof. O. C. Marsh. In preparation.
Of these *Monographs*, Nos. II, III, IV, V, VI, and VII are now published, viz:

II. *Tertiary History of the Grand Cañon District*, with atlas, by C. E. Dutton, Capt. U. S. A. 1882. 4°. 264 pp. 42 pl. and atlas of 26 double sheets folio. Price $14.12.

III. *Geology of the Comstock Lode and Washoe District*, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. *Comstock Mining and Miners*, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. *Copper-bearing Rocks of Lake Superior*, by Prof. R. D. Irving. 1883. 4°. xiv, 464 pp. 29 pl. Price $—.

VI. *Contributions to the Knowledge of the Older Mesozoic Flora of Virginia*, by William M. Fontaine. 1883. 4°. xix, 144 pp. 54 l. 54 pl. Price $—.

VII. *Silver-lead Deposits of Eureka, Nevada*, by Joseph S. Curtis. 1884. 4°. xii, 200 pp. 15 pl. Price $—.

Nos. VIII and IX are in press and will soon appear. The others, to which numbers are not assigned, are in preparation.

### BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper, and be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1, 2, 3, 4, 5, 6, 7, and 8 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 40 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the Coining Value of Troy Ounces of Fine Metal, &c., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the Meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargement of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. Price 10 cents.

### STATISTICAL PAPERS.

A fourth series of publications having special reference to the mineral resources of the United States is contemplated. Of that series the first has been published, viz: Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Correspondence relating to the publications of the Survey, and all remittances, which must be by postal note or money order, should be addressed to the

DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY,
*Washington, D. C.*

WASHINGTON, D. C., *August* 30, 1884.

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# BULLETIN

OF THE

# UNITED STATES

# GEOLOGICAL SURVEY

## No. 9

WASHINGTON
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1884

UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL DIRECTOR

# A REPORT OF WORK DONE

IN THE

# WASHINGTON LABORATORY

DURING THE

# FISCAL YEAR 1883-'84

F. W. CLARKE CHIEF CHEMIST
T. M. CHATARD ASSISTANT CHEMIST

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

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## INTRODUCTORY.

The present bulletin contains the more important results obtained in the chemical laboratory of the United States Geological Survey at Washington, between December 12, 1883, and June 30, 1884. The work here reported was almost wholly done by Dr. T. M. Chatard and myself, and represents the first fiscal year of our laboratory organization. Other work, carried forward in this laboratory by Dr. F. A. Gooch, and relating mainly to the rocks and waters of the Yellowstone National Park, is reserved for a future bulletin.

In addition to the analyses here published, a considerable number of assays, mineral determinations, and qualitative examinations have been made. Several researches have also been begun, but are not yet advanced enough to warrant any announcement. Other bulletins will be issued from time to time, as fast as material accumulates.

F. W. CLARKE.

# WORK DONE IN THE WASHINGTON LABORATORY DURING THE FISCAL YEAR 1883--'84.

## MINERAL, ROCK, AND ORE ANALYSES.

The mineralogical work of the division of chemistry has been done in close co-operation with the mineral department of the National Museum. Some of the material studied has been received through the latter institution; some has been brought in by field parties of the Survey; some represents our own summer collecting. The rocks, clays, etc., analyzed, have been submitted by other divisions of the survey, and will not be specially discussed in this bulletin. The only novelty in the methods of analysis has been in the use of the bismuth oxide process for the estimation of the alkalies in silicates. This process, as modified by Dr. Chatard, is described later.

### GAHNITE FROM GILMORE'S MICA MINE, MOUNTGOMERY COUNTY, MARYLAND.

The locality at which this mineral was found is 12 miles north of Washington, near Colesville, Maryland. The mine has yielded a considerable quantity of merchantable mica, which occurs in the usual granite vein, associated with quartz, albite, garnet, black tourmaline, and beryl. The last-named mineral is abundant in large but ill-formed crystals. But one specimen of the gahnite was obtained; a dark-green massive specimen, filling a cavity in altered feldspar. Specific gravity 4.59. Analysis by T. M. Chatard:

| | |
|---|---|
| Ignition | 30 |
| $SiO_2$ | 57 |
| $Al_2O_3$ | 55.46 |
| $Fe_2O_3$ | 2.77 |
| ZnO | 40.07 |
| MgO | 59 |
| CuO | undet. |
| | 99.76 |

### JADE AND PECTOLITE FROM ALASKA.

Among the Eskimo implements collected by the U. S. Signal Service at Point Barrow, Alaska, were a considerable number of a material which appeared to be jade. Of these there were two varieties; one pale apple-green, the other dark-green; both were highly polished, and exceedingly compact and tough. The specific gravity of the pale-green

variety was 2.873, that of the dark material was 3.012. Analyses (Clarke) gave results as follows:

| | Pale-green. | Dark-green. |
|---|---|---|
| $H_2O$ | 4.09 | 1.41 |
| $SiO_2$ | 58.94 | 57.01 |
| FeO | trace. | 6.96 |
| CaO | 33.21 | 12.75 |
| MgO | 1.43 | 21.30 |
| $Al_2O_3$ | 0.53 | 0.43 |
| $Na_2O$ | 2.57 | |
| | 100.23 | 99.90 |

The dark-green material is plainly jade, or nephrite, quite analogous in composition to that from the Swiss lake dwellings. The light-green mineral, on the other hand, agrees in composition with pectolite. It is easily fusible, and has, in short, all the essential properties of pectolite. It is, therefore, a new and interesting variety of that well-known species.

The Eskimo of Point Barrow say that the jade and jade-like minerals used by them come from some point to the eastward. The locality itself, we believe, has not yet been visited by civilized men. Whether both minerals are found at the same place or not cannot be stated; but we hope that before long more definite information may be secured.

### SAUSSURITE FROM CALIFORNIA.

Found in a gabbro collected by Mr. J. S. Diller, thirty-seven miles north of Pit River Ferry, Shasta County. The mineral is nearly white, with a greenish-gray cast, and has a specific gravity of 3.148. Associated with green diallage. Analysis by F. W. Clarke:

| | |
|---|---|
| Ignition | 2.42 |
| $SiO_2$ | 42.79 |
| $Al_2O_3$ | 29.43 |
| CaO | 18.13 |
| FeO | 3.65 |
| MgO | 1.40 |
| $Na_2O$ | 2.51 |
| | 100.33 |

### ALLANITE FROM TOPSHAM, MAINE.

Abundant in slender black prisms at Sprague's granite quarry. The crystals are usually much rusted upon the surface, and are known to the local quarrymen as "nails." Analysis by F. W. Clarke:[1]

| | |
|---|---|
| $H_2O$ | 4.13 |
| $SiO_2$ | 34.97 |
| $Al_2O_3$ | 12.63 |
| FeO | 18.11 |
| MnO | 2.89 |
| $Ce_2O_3$, $La_2O_3$, $Di_2O_3$ | 17.26 |
| CaO | 7.21 |
| MgO | 1.40 |
| | 98.73 |

[1] Compare analysis by F. C. Robinson, Amer. Jour. Sci., May, 1884.

The ferrous oxide carries with it some ferric oxide. As the analysis was made merely for the complete identification of the species, the troublesome separation of the cerium group oxides was not considered necessary. The mineral appears to vary considerably in different parts of the quarry.

BERYL FROM GREENE COUNTY, TENNESSEE.

A typical, bluish-green translucent beryl. Analysis by F. W. Clarke:

| | |
|---|---|
| $SiO_2$ | 65.39 |
| GlO | 13.35 |
| $Al_2O_3$ (tr. FeO) | 19.10 |
| Ignition | 1.76 |
| | 99.60 |

DAMOURITE FROM STONEHAM, ME.

Two specimens of a micaceous mineral from the topaz locality at Stoneham, collected by Mr. N. H. Perry, of South Paris, and sent by him to the National Museum, have been examined and prove to be different forms of damourite.

A. Subfibrous compact, light grayish green in color, greasy luster, associated with albite and topaz.

B. Broadly foliated micaceous, light grayish green, strong mother-of-pearl luster, also associated with topaz. Analyses (Chatard) as follows:

| | A. | B. |
|---|---|---|
| Ignition | 4.48 | 4.78 |
| $SiO_2$ | 45.19 | 45.34 |
| $Al_2O_3$ | 33.32 | 33.90 |
| FeO | 4.25 | 3.96 |
| MnO | 0.58 | 0.51 |
| CaO | trace. | 0.22 |
| MgO | 0.36 | 0.10 |
| $Na_2O$ | 1.57 | 1.49 |
| $K_2O$ | 11.06 | 10.73 |
| | 100.81 | 101.09 |

MARGARITE.

A. From Soapstone Hill, near Gainesville, Georgia. Bright pistachio green, subfibrous aggregate of extremely minute scales surrounding and radiating from a core of bright rose-pink corundum which is in places interlaminated by the margarite. A very handsome specimen on account of the contrast of color. From Mr. Theodore Moreno, of Gainesville, Georgia. G. = 3.00; H. = 3.5. Analysis (T. M. Chatard):

| | |
|---|---|
| $H_2O$ | 4.88 |
| $SiO_2$ | 31.72 |
| $Al_2O_3$ | 50.03 |
| FeO | trace. |
| CaO | 11.57 |
| MgO | 0.12 |
| $Na_2O$ | 2.26 |
| | 100.58 |

B. An altered crystal of corundum from Iredell County, North Carolina, showing a core of corundum surrounded by a yellowish-white, semi-micaceous, compact mineral more or less intermixed with small needles of black tourmaline. Analysis (Chatard) shows the micaceous mineral to be a margarite similar to that described by Dr. F. A. Genth as occurring at Hendrick's farm in the same county.

| | |
|---|---|
| $H_2O$ | 5.68 |
| $SiO_2$ | 31.15 |
| $Al_2O_3$ | 49.51 |
| $CaO$ | 11.13 |
| $MgO$ | 0.45 |
| $Na_2O$ | 2.74 |
| | 100.66 |

CIMOLITE FROM NORWAY, MAINE.

Among a collection of Maine minerals received from N. H. Perry, of South Paris, were several specimens of tourmaline and albite encrusted with a pink to rose-purple, earthy, alteration product. The color was found to be due to a little manganese, which was not, however, separately estimated. The analysis (Clarke) gave results approaching to those required by the rational formula $AlH_3(SiO_3)_3$, as the subjoined figures show:

| | Found. | Theory. |
|---|---|---|
| $H_2O$ | 9.53 | 10.4 |
| $SiO_2$ | 70.06 | 69.8 |
| $Al_2O_3$ (with MnO) | 17.19 | 19.8 |
| $Na_2O$ | 2.28 | ..... |
| $MgO$ | 0.80 | ..... |
| | 99.86 | 100.0 |

It will be observed at once that these results do not agree exactly with those commonly obtained for cimolite. They are too high in silica, and too low in water, and the formula deduced from them is somewhat novel. We are inclined to place the mineral, however, under cimolite, as being nearer to that species than to any other. Possibly the new formula represents the final outcome of an alteration process which ordinary cimolite has only partially undergone. Somewhat similar pink alteration products are not uncommon in the albitic granite veins of Maine and New Hampshire, and some, without analysis, have been supposed to be montmorillonite, like that of Branchville, Connecticut. A more thorough examination of such products is much to be desired.

HALLOYSITE FROM CALIFORNIA.

Collected by Ensign J. B. Bernadou, at the Detroit Copper Mine, near Mono Lake. The specimens consisted of irregular lumps, covered and seamed with a black coating of the oxides of copper and manganese.

The color of the pure mineral was white, with a very faint tinge of blue. Analysis by F. W. Clarke.

| | |
|---|---|
| $H_2O$ | 18.95 |
| $SiO_2$ | 42.91 |
| $Al_2O_3$ | 38.13 |
| | 99.99 |

PROCHLORITE.

A dark-green chlorite, collected by Mr. G. P. Merrill on Foundry Run, Georgetown, D. C., may be assigned to the above-named species. The mineral is very dark in color, scaly-crystalline, and occurs in quite fine specimens. Analysis by F. W. Clarke.

| | |
|---|---|
| $H_2O$ | 14.43 |
| $SiO_2$ | 25.45 |
| $MgO$ | 15.04 |
| $Al_2O_3$ | 17.88 |
| $FeO$ | 24.98 |
| $Na_2O$ | 0.67 |
| | 98.45 |

The iron is all reckoned as ferrous iron, although part of it is undoubtedly ferric.

SO-CALLED "ALUM ROCK" FROM GRANT COUNTY, NEW MEXICO.

Six samples were received from Hon. W. S. Rosecrans. The material is found at the headwaters of the Gila River, about 40 miles north of Silver City, and is said to cover about 2,000 acres. The specimens may be described as follows:

A. Pinkish crusts.
B. Yellowish crusts.
C. Drab crusts.
D. White crusts.
E. Fibrous mineral of silky luster.
F. "Gray alum rock."

Analyses by F. W. Clarke.

A.

| | |
|---|---|
| $Al_2O_3$ | 15.52 |
| $SO_3$ | 34.43 |
| $H_2O$ | 42.56 |
| Insoluble residue | 7.62 |
| | 100.13 |

This substance is alunogen. So, also, but impure, containing iron, are B, C, and D. Of these only rough analyses were made.

| | B. | C. | D. |
|---|---|---|---|
| Ignition | 16.20 | 71.28 | 55.41 |
| $Al_2O_3+Fe_2O_3$ | 4.95 | 15.81 | 9.19 |
| Insoluble residue | 78.95 | 12.27 | 33.19 |
| | 100.10 | 99.36 | 97.79 |

The analysis of E shows it to be halotrichite. Only a trace of ferric iron is present. Color nearly white, slightly grayish. Asbestiform.

E.

| | |
|---|---|
| $Al_2O_3$ | 7.27 |
| FeO | 13.59 |
| $SO_3$ | 37.19 |
| $H_2O$ | 40.62 |
| Insoluble | 0.50 |
| | 99.17 |

F, which was not analyzed, is merely an impure mixture of alunogen and halotrichite.

SCORIACEOUS OBSIDIAN, SOUTHEAST SIDE OF MONO VALLEY, CALIFORNIA.

A grayish-white rock which forms a large portion of the Mono craters. Collected by I. C. Russell. Analysis by T. M. Chatard.

| | |
|---|---|
| Ignition | 2.90 |
| $SiO_2$ | 74.05 |
| $Al_2O_3$ (trace $Fe_2O_3$) | 13.85 |
| CaO | 0.90 |
| MgO | 0.07 |
| $K_2O$ | 4.31 |
| $Na_2O$ | 4.60 |
| | 99.98 |

WHITE POWDER FROM LAHONTAN LAKE-BEDS, TRUCKEE RIVER.

A volcanic dust which fell in the quaternary Lake Lahontan. Supposed to have been erupted from the Mono craters. Collected by I. C. Russell. Analysis by T. M. Chatard.

| | |
|---|---|
| $H_2O$ | 3.91 |
| $SiO_2$ | 71.15 |
| $Al_2O_3$ (+ $Fe_2O_3$) | 15.95 |
| CaO | 0.85 |
| MgO | 0.41 |
| MnO | trace. |
| $K_2O$ | 3.36 |
| $Na_2O$ | 4.94 |
| | 100.57 |

MARL FROM "WHITE TERRACE," 3 MILES WEST OF MULLEN'S SPRINGS, WEST SHORE OF PYRAMID LAKE, NEVADA.

Mostly deposited from the waters of the prehistoric Lake Lahontan. Collected by I. C. Russell. Analysis by T. M. Chatard.

| | |
|---|---|
| $CaCO_3$ | 64.82 |
| $SiO_2$ | 22.00 |
| $Al_2O_3$ | 5.14 |
| $Fe_2O_3$ | 2.04 |
| CaO | 0.93 |
| MgO | 1.89 |
| $H_2O$ | 3.32 |
| | 100.14 |

TWO CLAYS FROM HUMBOLDT RIVER BRIDGE, MILL CITY, NEVADA.

A. From Upper Lahontan Lake-beds. B. From Lower Lahontan Lake-beds. Collected by I. C. Russell. Analyzed by T. M. Chatard. Color in both cases grayish.

| | A. | B. |
|---|---|---|
| Ignition | 9.78 | 13.00 |
| $SiO_2$ | 56.30 | 56.70 |
| $Al_2O_3$ | 16.22 | *13.01 |
| $Fe_2O_3$ | 5.06 | ..... |
| CaO | 5.45 | 10.26 |
| MgO | 2.64 | 3.19 |
| $K_2O$ | 2.17 | 2.16 |
| $Na_2O$ | 2.60 | 1.91 |
| | 100.54 | 100.26 |

* With a little $Fe_2O_3$.

BASALT FROM MOUNT THIELSON, OREGON.

Material collected by J. S. Diller; by whom also the lithological separations were made. Analyses of rock and component parts as follows:

A. Basalt. F. W. Clarke.

B. Groundmass. T. M. Chatard.

C. Hypersthene. T. M. Chatard.

D. Feldspar, specific gravity, 2.637–2.714. T. M. Chatard.

E. Feldspar, specific gravity, 2.714–2.877. T. M. Chatard.

| | A. | B. | C. | D. | E. |
|---|---|---|---|---|---|
| Ignition | .60 | .52 | ..... | .40 | .66 |
| $SiO_2$ | 55.66 | 53.85 | 53.31 | 51.95 | 55.48 |
| $TiO_2$ | undet. | ..... | ..... | trace. | .39 |
| $Al_2O_3$ | 13.93 | 22.95 | 5.99 | 28.84 | 26.91 |
| $Fe_2O_3$ | 8.73 | 4.59 | ..... | 2.24 | 2.33 |
| FeO | | | 13.43 | ..... | ..... |
| CaO | 7.99 | 8.41 | 3.66 | 11.43 | 8.11 |
| MgO | 4.86 | 3.06 | 21.66 | 1.34 | 2.27 |
| $Na_2O$ | 2.12 | 2.16 | ..... | 3.23 | 3.14 |
| $K_2O$ | .48 | 2.67 | ..... | .59 | .72 |
| | 99.39 | 100.23 | 98.11 | 100.00 | 100.00 |

In B a trace of $P_2O_5$ was found, and in C a trace of manganese. D and E are near labradorite, and are evidently mixtures. C, D, and E were received in very small quantities; not sufficient for full analysis. D and E therefore were treated with hydrofluoric acid, in order to render possible the estimation of the alkalies, and silica was taken by difference.

Less than half a gramme of a fulgurite, formed by the fusion of this basalt by lightning, was also partially analyzed. The results (Clarke) are as follows:

| | |
|---|---|
| Ignition | 1.11 |
| $SiO_2$ | 55.04 |
| $Al_2O_3$, $Fe_2O_3$ | 28.99 |
| CaO | 7.86 |
| MgO | 5.85 |
| Alkalies | undet. |
| | 98.85 |

BASALT FROM PIT RIVER, NORTH OF BURNEY VALLEY, CALIFORNIA.

Collected by J. S. Diller. Analysis by F. W. Clarke.

| | |
|---|---|
| Ignition | 1.54 |
| $SiO_2$ | 51.92 |
| $Al_2O_3$ | 19.76 |
| FeO (includes a little $Fe_2O_3$) | 11.21 |
| CaO | 9.30 |
| MgO | 3.38 |
| $Na_2O$ | 2.16 |
| $K_2O$ | 0.60 |
| | 99.87 |

DACITES FROM LASSEN'S PEAK, CALIFORNIA.

Collected by J. S. Diller. Analyses by T. M. Chatard.

A. Gray dacite.

B. Reddish dacite.

C. Inclusion in dacite.

| | A. | B. | C. |
|---|---|---|---|
| Ignition | 0.56 | 0.44 | 1.35 |
| $SiO_2$ | 69.51 | 68.20 | 58.97 |
| $Al_2O_3$ | 15.75 | 16.98 | 18.60 |
| $Fe_2O_3$ | 3.34 | 3.75 | 5.94 |
| CaO | 1.71 | 4.33 | 2.84 |
| MgO | 2.09 | 2.07 | 6.89 |
| $Na_2O$ | 3.89 | 2.98 | 3.05 |
| $K_2O$ | 3.34 | 1.52 | 2.24 |
| $P_2O_5$ | trace | ..... | undet. |
| | 100.19 | 100.27 | 99.88 |

TWO SAMPLES OF LIMESTONE FROM MOUNDSVILLE NARROWS, TWELVE MILES BELOW WHEELING, W. VA.

A. Upper ledge. B. Lower ledge. Analyses by T. M. Chatard.

| | A. | B. |
|---|---|---|
| Moisture | 0.05 | 0.10 |
| Insoluble | 10.33 | 1.58 |
| $CO_2$ | 39.18 | 43.16 |
| CaO | 48.02 | 53.26 |
| MgO | 1.08 | 0.93 |
| $Fe_2O_3$ | 0.90 | 0.96 |
| MnO and $P_2O_5$ | traces | traces |
| | 99.56 | 99.94 |

EQUIVALENT TO—

| | | |
|---|---|---|
| Moisture | 0.05 | 0.10 |
| $CaCO_3$ | 85.75 | 95.10 |
| $MgCO_3$ | 2.26 | 1.95 |
| $FeCO_3$ | 0.73 | 0.79 |
| Sand, clay, and $Fe_2O_3$ | 10.77 | 2.00 |
| | 99.56 | 99.94 |

MAGNETIC IRON ORE FROM NEAR BOZEMAN, MONTANA.

Found in the Gallatin Range, between Middle and Bozeman Creeks, southwest of Bozeman.

Received from A. C. Peale. Analysis by T. M. Chatard.

| | |
|---|---|
| Insoluble ($SiO_2$) | 0.165 |
| $Fe_3O_4$ | 96.49 |
| $FeS_2$ (S=0.171) | 0.321 |
| $Al_2O_3$ | 0.04 |
| MnO | 0.93 |
| CaO | trace. |
| MgO | 0.072 |
| $TiO_2$ | 2.71 |
| $P_2O_5$ | 0.012 |
| | 100.740 |

The titanium was determined in a separate portion, and is probably high from presence of iron.

LIMONITE FROM CANAAN MT., TUCKER COUNTY, W. VA.

Analysis by T. M. Chatard.

| | |
|---|---|
| $Fe_2O_3$ | 80.53 |
| Moisture | 13.20 |
| $SiO_2$ | 1.95 |
| $P_2O_5$ | 1.98 |
| S | trace. |
| CaO | 2.34 |
| MnO | none. |
| | 100 00 |

COAL FROM CRANSTON, R. I.

Analysis by F. A. Gooch. Specific gravity, 2.209 at 150.

| | |
|---|---|
| Water | 0.24 |
| Volatile matter | 4.49 |
| Fixed carbon | 82.20 |
| Ash | 13.07 |
| | 100.00 |
| Sulphur | 0.34 |

## WATER ANALYSES.

With the exceptions of the waters from Montana, the Utah Hot Springs, and the Virginia Hot Springs, the following waters were collected by the Division of the Great Basin, under the direction of Messrs. G. K. Gilbert and I. C. Russell. For sufficient reasons, it was necessary to abbreviate the analyses as much as possible, and this was done by avoiding the direct estimation of carbonic acid. Whenever carbonates were proved to be present all the other ingredients of a water were determined and the carbonic acid, reckoned as $CO_3$, was taken as the difference between the sum of their weights and the weight of the total solid residue. In computing the probable compounds formed by the union of acids and bases, the chlorides and sulphates were first disposed of, and the bases in excess were then calculated as carbonates. This procedure gave usually a summation a little greater or less than the total solids directly found upon evaporating the water to dryness; and the variation of the result from 100 per cent. afforded a means of estimating the probable accuracy of the analysis. In most cases the samples of water received were insufficient for a search after the less common elements. These, therefore, were necessarily ignored, except in so far as the spectroscope or qualitative tests could reveal their presence. The gaseous contents of the waters received no consideration. In certain respects, therefore, all the analyses are to be regarded as imperfect; although they are fully adequate for the geological purposes which led to their being made.

Each analysis is stated in three columns. First, the actual weight in grammes to the liter of each constituent. Second, the percentage of each relatively to the total solid residue. Third, the probable combination, also in grammes to the liter. The second column gives a means of comparing different waters as to their composition, irrespective of their greater or less salinity. The third column was computed in the simplest terms, and not with reference to complex and doubtful hypotheses.

### PYRAMID LAKE, NEVADA.

Four samples of water were analyzed (Clarke), as follows:

A. Water of north end of the lake, near the surface.

B. Water of north end of the lake, depth of 108 meters.

C. Water of south end of the lake, near the surface.

D. Water of south end of the lake, depth of 61 meters.

All four samples contained suspended flakes of silicious and calcareous matter.

A.

[Total solids, 3.4987 grammes to liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.0412 | 1.17 | $SiO_2$ | 0.0412 |
| $SO_4$ | 0.1803 | 5.15 | KCl | 0.1474 |
| Cl | 1.4298 | 40.87 | NaCl | 2.2411 |
| Ca | 0.0179 | 0.51 | $Na_2SO_4$ | 0.2667 |
| Mg | 0.0800 | 2.29 | $Na_2CO_3$ | 0.4738 |
| Na | 1.1731 | 33.53 | $CaCO_3$ | 0.0447 |
| K | 0.0766 | 2.19 | $MgCO_3$ | 0.2800 |
| | 2.9989 | | | 3.4949 |
| $CO_2$ | 0.4998 | 14.29 | 99.94 per cent. accounted for. | |
| | 3.4987 | 100.00 | | |

B.

[Total solids: 3.4837 grammes to liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.0200 | 0.57 | $SiO_2$ | 0.0200 |
| $SO_4$ | 0.1850 | 5.31 | KCl | 0.1381 |
| Cl | 1.4342 | 41.17 | NaCl | 2.2550 |
| Ca | 0.0179 | 0.51 | $Na_2SO_4$ | 0.2787 |
| Mg | 0.0805 | 2.31 | $Na_2CO_3$ | 0.4756 |
| Na | 1.1817 | 33.92 | $CaCO_3$ | 0.0447 |
| K | 0.0723 | 2.07 | $MgCO_3$ | 0.2818 |
| | 2.9916 | | | 3.4889 |
| $CO_2$ | 0.4921 | 14.14 | Total, 100.15 per cent. | |
| | 3.4837 | 100.00 | | |

C.

[Total solids: 3.4725 grammes to liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.0425 | 1.22 | $SiO_2$ | 0.0425 |
| $SO_4$ | 0.1772 | 5.10 | KCl | 0.1374 |
| Cl | 1.4288 | 41.15 | NaCl | 2.2466 |
| Ca | | | $Na_2SO_4$ | 0.2621 |
| Mg | 0.0752 | 2.17 | $Na_2CO_3$ | 0.4940 |
| Na | 1.1826 | 34.06 | $CaCO_3$ | |
| K | 0.0719 | 2.07 | $MgCO_3$ | 0.2632 |
| | 2.9782 | | | 3.4458 |
| $CO_2$ | 0.4943 | 14.23 | 99.23 per cent. accounted for. | |
| | 3.4725 | 100.00 | | |

D.

[Total solids: 3.4900 grammes to liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.0300 | 0.86 | $SiO_2$ | 0.0300 |
| $SO_4$ | 0.1864 | 5.34 | KCl | 0.1387 |
| Cl | 1.4271 | 40.99 | NaCl | 2.2428 |
| Ca | | | $Na_2SO_4$ | 0.2757 |
| Mg | 0.0832 | 2.38 | $Na_2CO_3$ | 0.4834 |
| Na | 1.1809 | 33.84 | $CaCO_3$ | |
| K | 0.0726 | 2.13 | $MgCO_3$ | 0.2912 |
| | 2.9802 | | | 3.4618 |
| $CO_2$ | 0.5098 | 14.46 | 99.19 per cent. accounted for. | |
| | 3.4900 | 100.00 | | |

The slight differences between these analyses may be attributed in part to the fact that the lake is fed at its southern end by a large stream of fresh water. The four percentage columns may be conveniently compared in the following table:

| | A. | B. | C. | D. |
|---|---|---|---|---|
| Total solids | 3.4987 | 3.4837 | 3.4725 | 3.4900 |
| $SiO_2$ | 1.17 | 0.57 | 1.22 | 0.86 |
| $SO_4$ | 5.15 | 5.31 | 5.10 | 5.34 |
| Cl | 40.87 | 41.17 | 41.15 | 40.99 |
| Ca | 0.51 | 0.51 | | |
| Mg | 2.29 | 2.31 | 2.17 | 2.38 |
| Na | 33.53 | 33.92 | 34.06 | 33.84 |
| K | 2.19 | 2.07 | 2.07 | 2.13 |
| $CO_2$ | 14.29 | 14.14 | 14.23 | 14.46 |
| | 100.00 | 100.00 | 100.00 | 100.00 |

WINNEMUCCA LAKE, NEVADA.

Specific gravity of water, 1.001, at 17°. Analysis by F. W. Clarke.

[Total solids: 3.6025 grammes to liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.0275 | 0.76 | $SiO_2$ | 0.0275 |
| $SO_4$ | 0.1333 | 3.70 | KCl | 0.1310 |
| Cl | 1.6934 | 47.01 | NaCl | 2.6877 |
| Ca | 0.0196 | 0.54 | $Na_2SO_4$ | 0.1972 |
| Mg | 0.0173 | 0.48 | $Na_2CO_3$ | 0.4068 |
| Na | 1.2970 | 36.00 | $CaCO_3$ | 0.0254 |
| K | 0.0686 | 1.90 | $MgCO_3$ | 0.0494 |
| | 3.2567 | | | 3.5247 |
| $CO_2$ | 0.3458 | 9.61 | 98.44 per cent. accounted for. | |
| | 3.6025 | 100.00 | | |

WALKER LAKE, NEVADA.

Two analyses (Clarke) were made; one of a sample taken just below the surface, the other of water from a depth of 65.5 meters. Both were collected by Mr. I. C. Russell.

A.—*Surface sample.*

[Total solids: 2.5155 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.0075 | 0.29 | $SiO_2$ | 0.0075 |
| $SO_4$ | 0.5275 | 20.96 | NaCl | 0.9681 |
| Cl | 0.5875 | 23.36 | $Na_2SO_4$ | 0.7803 |
| Ca | 0.0267 | 1.06 | $Na_2CO_3$ | 0.5157 |
| Mg | 0.0391 | 1.55 | $CaCO_3$ | 0.0667 |
| Na | 0.8577 | 34.11 | $MgCO_3$ | 0.1369 |
| K | trace. | | | 2.4752 |
| | 2.0460 | | 98.39 per cent. accounted for. | |
| $CO_2$ | 0.4695 | 18.67 | | |
| | 2.5155 | 100.00 | | |

B.—*Lower sample.*

[Total solids: 2.4875 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.0075 | .30 | $SiO_2$ | 0.0075 |
| $SO_4$ | 0.5125 | 20.60 | NaCl | 0.9558 |
| Cl | 0.5800 | 23.32 | $Na_2SO_4$ | 0.7580 |
| Ca | 0.0176 | .71 | $Na_2CO_3$ | 0.5339 |
| Mg | 0.0375 | 1.51 | $CaCO_3$ | 0.0440 |
| Na | 0.8530 | 34.29 | $MgCO_3$ | 0.1313 |
| K | trace. | | | 2.4305 |
| | 2.0081 | | 97.66 per cent. accounted for. | |
| $CO_2$ | 0.4794 | 19.27 | | |
| | 2.4875 | 100.00 | | |

Mud taken from the bottom of the Lake, at a depth of 68 meters, was also examined qualitatively by Dr. Chatard. The portion soluble in water contained chlorides of sodium and potassium, with some sulphates and traces of borates. The residue, extracted with hydrochloric acid, was found to contain carbonates of lime and magnesia, with some phosphates, iron, alumina, and alkalies. The insoluble portion was impure silica.

WALKER RIVER, NEVADA.

The sample of water was collected immediately below the junction of the east and west branches. Analysis by F. W. Clarke.

[Total solids: 0.1800 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0225 | 12.50 | $SiO_2$ | 0.0225 |
| $SO_4$ | .0284 | 15.77 | NaCl | 0.0216 |
| Cl | .0131 | 7.28 | $Na_2SO_4$ | 0.0421 |
| Ca | .0228 | 12.66 | $Na_2CO_3$ | 0.0224 |
| Mg | .0038 | 2.12 | $CaCO_3$ | 0.0570 |
| Na | .0318 | 17.67 | $MgCO_3$ | 0.0123 |
| | .1224 | | | 0.1789 |
| $CO_2$ | .0576 | 32.00 | 99.39 per cent. accounted for. | |
| | .1800 | 100.00 | | |

HUMBOLDT RIVER, NEVADA.

Sample collected at Stone House. Analysis by T. M. Chatard.

[Total solids: 0.3615 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0326 | 9.03 | $SiO_2$ | .0326 |
| $Al_2O_3$ | .0013 | 0.37 | $Al_2O_3$ | .0013 |
| $SO_4$ | .0477 | 13.12 | KCl | .0157 |
| Cl | .0075 | 2.08 | $K_2CO_3$ | .0046 |
| Ca | .0489 | 13.53 | $Na_2CO_3$ | .0550 |
| Mg | .0124 | 3.46 | $Na_2SO_4$ | .0705 |
| Na | .0467 | 12.92 | $CaCO_3$ | .1222 |
| K | .0100 | 2.77 | $MgCO_3$ | .0434 |
| | .2071 | | | .3453 |
| $CO_2$ | .1544 | 42.72 | 95.52 per cent. accounted for. | |
| | .3615 | 100.00 | | |

If the loss in the last column is due to the presence of alkaline bicarbonates, and reckoned in the latter form to make up 100 per cent., we have—

$Na_2CO_3$ ..... .0200
$NaHCO_3$ ..... .0512

HOT SPRING, WARD'S RANCH, FOOT OF GRANITE MOUNTAIN, NEVADA.

## Analysis by T. M. Chatard.

[Total solids: 1.1902 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.1136 | 9.60 | $SiO_2$, free | 0.0180 |
| $SO_4$ | 0.3901 | 32.97 | $Na_2SiO_3$ | 0.1942 |
| Cl | 0.2396 | 20.25 | $Na_2SO_4$ | 0.4267 |
| $CO_3$ | trace | | NaCl | 0.3665 |
| Ca | 0.0367 | 3.10 | KCl | 0.0363 |
| Mg | 0.0034 | 0.29 | $CaSO_4$ | 0.1247 |
| Na | 0.3554 | 30.03 | $MgSO_4$ | 0.0179 |
| K | 0.0191 | 1.61 | | 1.1834 |
| Li | trace | | | |
| O for $SiO_2$ | 0.0255 | 2.15 | 99.43 per cent. accounted for. | |
| | 1.1834 | 100.00 | | |

HOT SPRING, AT HOT SPRING STATION, NEVADA, C. P. R. R.

## Analysis by T. M. Chatard.

[Total solids: 2.4924 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.2788 | 11.14 | $SiO_2$, free | 0.2060 |
| $SO_4$ | 0.3555 | 14.25 | $Na_2SiO_3$ | 0.1430 |
| Cl | 0.9679 | 38.79 | NaCl | 1.4946 |
| Ca | 0.0305 | 1.23 | $Na_2SO_4$ | 0.4039 |
| Mg | 0.0010 | 0.04 | KCl | 0.1278 |
| Al | 0.0010 | 0.04 | $Al_2(SO_4)_3$ | 0.0063 |
| Na | 0.7743 | 31.04 | $MgSO_4$ | 0.0050 |
| K | 0.0669 | 2.69 | $CaSO_4$ | 0.1037 |
| Li | trace. | | | 2.4953 |
| O in $SiO_2$ | 0.0194 | .78 | | |
| | 2.4953 | 100.00 | 100.11 per cent. accounted for. | |

LARGER SODA LAKE, NEAR RAGTOWN, NEVADA.

Specific gravity of water, 1.101. Two analyses (Chatard) were made, one of a sample taken just below the surface, the other of water from a depth of 30.5 meters.

A.—*Surface sample.*

[Total solids: 125.1300 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.304 | 0.24 | $SiO_2$ | 0.304 |
| $SO_4$ | 12.960 | 10.36 | KCl | 4.820 |
| Cl | 45.690 | 36.51 | NaCl | 71.470 |
| $B_4O_7$ | 0.314 | 0.25 | $Na_2SO_4$ | 19.170 |
| Mg | 0.270 | 0.22 | $Na_2CO_3$ | 26.410 |
| Na | 45.840 | 36.63 | $Na_2B_4O_7$ | 0.404 |
| K | 2.520 | 2.01 | $MgCO_3$ | 0.940 |
| | 107.898 | | | 123.518 |
| $CO_2$ | 17.232 | 13.78 | 98.71 per cent. accounted for. | |
| | 125.130 | 100.00 | | |

If the loss in the last column be reckoned as due to the presence of bicarbonates, it gives, to make up 100 per cent.:

| | |
|---|---|
| $Na_2CO_3$ | 23.640 |
| $NaHCO_3$ | 4.382 |

B.—*Lower sample.*

[Total solids: 125.1500 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.310 | 0.25 | $SiO_2$ | 0.310 |
| $SO_4$ | 13.150 | 10.50 | KCl | 5.110 |
| Cl | 44.270 | 35.38 | NaCl | 68.930 |
| $B_4O_7$ | 0.327 | 0.26 | $Na_2SO_4$ | 19.450 |
| Mg | 0.270 | 0.21 | $Na_2CO_3$ | 24.840 |
| Na | 44.270 | 35.38 | $Na_2B_4O_7$ | 0.417 |
| K | 2.670 | 2.13 | $MgCO_3$ | 0.940 |
| | 105.267 | | | 119.997 |
| $CO_2$ | 19.883 | 15.89 | 95.88 per cent. accounted for. | |
| | 125.150 | 100.00 | | |

Reckoning the loss in the last column as in the case of the surface sample, we have—

| | |
|---|---|
| $Na_2CO_3$ | 16.040 |
| $NaHCO_3$ | 13.953 |

From the waters of this lake sodium carbonate is manufactured upon a commercial scale. Several brines and products obtained in this manufacture were qualitatively examined by Dr. Chatard. A more complete investigation may be undertaken at some future time. A pale pink-colored brine, from which summer soda had been taken, and in which salt had begun to crystallize, was found to contain carbonates, chlorides, and sulphates of sodium and potassium, with some alkaline phosphates and borates. The pink color was probably due to organic matter. A concentrated brine from the Little Soda Lake contained similar ingredients, minus the phosphates. In a crystalline mass from a vat at the same locality the same constituents were found, with phosphates and a trace of lime. From this vat five annual crops of soda were said to have been taken. The sodium carbonate as it goes to market from the smaller Soda Lake, contains as impurities, sand, clay, considerable chloride, some sulphate, a little borate, a trace of phosphate, and some potassium salts.

### MONO LAKE, CALIFORNIA.[1]

A sample of water taken near the surface. Analysis by T. M. Chatard. Specific gravity, 1.045 at 15°.5.

[Total solids: 51.8500 grammes to the liter.][1]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.2800 | 0.54 | SiO | 0.2800 |
| $SO_4$ | 6.8100 | 13.11 | KCl | 2.2300 |
| Cl | 12.1300 | 23.39 | NaCl | 18.2200 |
| $B_4O_7$ | 0.1600 | 0.34 | $Na_2SO_4$ | 10.0700 |
| Ca | 0.2900 | 0.55 | $Na_2B_4O_7$ | 0.2000 |
| Mg | 0.1300 | 9.28 | $Na_2CO_3$ | 19.4900 |
| Na | 18.9100 | 36.46 | $CaCO_3$ | 0.6800 |
| K | 1.1600 | 2.23 | $MgCO_3$ | 0.3600 |
| | 39.8700 | | | 51.5300 |
| $CO_2$ | 11.9800 | 23.10 | 99.60 per cent. accounted for. | |
| | 51.8500 | 100.00 | | |

Mud from the bottom of the lake, taken at a depth of over 30 meters, was also examined qualitatively. The portion soluble in water contained chlorides of potassium and sodium, *no* sulphates, some carbonates, and traces of sulphides. The portion soluble in hydrochloric acid contained iron, alumina, lime, and alkalies, with a little boric acid. The insoluble residue consisted of sand and silica.

[1] A second sample of Mono Lake water, taken from a depth of 30 meters, contained 52.8560 grammes to the liter.

SPRING ON TUFA CRAG, IN MONO LAKE.

Analysis by T. M. Chatard.

[Total solids: 0.2918 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0178 | 6.10 | $SiO_2$ | .0178 |
| $SO_4$ | .0546 | 18.71 | KCl | .0169 |
| Cl | .0144 | 4.03 | NaCl | .0104 |
| Ca | .0414 | 14.19 | $Na_2SO_4$ | .0709 |
| Mg | .0044 | 1.51 | $Na_2CO_3$ | .0506 |
| Na | .0513 | 17.58 | $CaCO_3$ | .1035 |
| K | .0088 | 3.02 | $MgCO_3$ | .0154 |
| | .1927 | | | .2945 |
| $CO_2$ | .0991 | 33.96 | Total, 100.91 per cent. | |
| | .2918 | 100.00 | | |

The water of the "Petroleum Spring," on an island in Mono Lake, yielded a solid residue of 0.8775 gramme to the liter. It contains carbonates, chlorides, and silicates; the bases being sodium, potassium, calcium, magnesium, and aluminum.

WARM SPRING, AT WARM SPRING STATION, MONO BASIN.

Analysis by T. M. Chatard.

[Total solids: 2.0850 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.1545 | 7.46 | $Al_2O_3$ | 0.0018 |
| $SO_4$ | 0.3131 | 15.13 | KCl | 0.1203 |
| Cl | 0.2272 | 10.98 | NaCl | 0.2799 |
| Ca | 0.0589 | 2.84 | $Na_2SO_4$ | 0.4631 |
| Mg | 0.0604 | 2.92 | $Na_2SiO_3$ | 0.2480 |
| Na | 0.6116 | 29.56 | $Na_2CO_3$ | 0.5972 |
| K | 0.0630 | 3.05 | $CaCO_3$ | 0.1475 |
| Li | trace. | | $MgCO_3$ | 0.2114 |
| $Al_2O_3$ | 0.0018 | 0.09 | | 2.0692 |
| | 1.4935 | | 99.24 per cent. accounted for. | |
| $CO_2$ | 0.5945 | 27.97 | | |
| | 2.0850 | 100.00 | | |

BOILING SPRING, FOUR MILES S. E. OF SHAFFER'S RANCH, HONEY LAKE VALLEY, CALIFORNIA.

Analysis by T. M. Chatard.

[Total solids: 1,0218 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.1310 | 12.83 | $SiO_2$, free | 0.1006 |
| $SO_4$ | 0.3492 | 34.19 | $Na_2SiO_3$ | 0.0613 |
| Cl | 0.2070 | 20.27 | $Na_2SO_4$ | 0.4715 |
| Ca | 0.0121 | 1.18 | NaCl | 0.3266 |
| Mg | 0.0004 | 0.04 | KCl | 0.0180 |
| Na | 0.3040 | 29.78 | $CaSO_4$ | 0.0409 |
| K | 0.0094 | 0.92 | $MgSO_4$ | 0.0020 |
| O for $SiO_2$ | 0.0060 | 0.79 | | 1.0211 |
| | 1.0211 | 100.00 | 99.93 per cent. accounted for. | |

Two other springs in Honey Lake Valley were examined qualitatively. In the water of the High Rock Spring were found carbonates, chlorides, and sulphates of calcium, magnesium, sodium and potassium, with a little silica. The Lower Hot Spring contained chlorides and sulphates of the same bases.

LAKE TAHOE, CALIFORNIA.

Analysis by F. W. Clarke.

[Total solids: 0.0730 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0137 | 18.77 | $SiO_2$ | .0137 |
| $SO_4$ | .0054 | 7.40 | KCl | .0034 |
| Cl | .0023 | 3.14 | NaCl | .0012 |
| Ca | .0093 | 12.74 | $K_2SO_4$ | .0034 |
| Mg | .0030 | 4.11 | $Na_2SO_3$ | .0052 |
| Na | .0078 | 10.00 | $Na_2CO_3$ | .0117 |
| K | .0033 | 4.52 | $CaCO_3$ | .0233 |
| | .0443 | | $MgCO_3$ | .0105 |
| $CO_3$ | .0287 | 39.32 | | .0723 |
| | .0730 | 100.00 | 99.04 per cent. accounted for. | |

ABERT LAKE, OREGON.

The water of this lake was collected by I. C. Russell, at a point about 150 meters off from the west shore. It was analyzed by Mr. F. W. Taylor, of the Smithsonian Institution, and the analysis is here included

merely for the purpose of completing the series of waters specially examined for the division of the Great Basin. Specific gravity, 1.02317

*Contents in one liter.*

| | |
|---|---|
| $SiO_2$ | 0.065 |
| NaCl | 7,217 |
| KCl | 8.455 |
| $K_2SO_4$ | 0.921 |
| $K_2CO_3$ | 10.691 |
| $MgCO_3$ | 10.006 |
| | 27.355 |

An efflorescence from the north shore of the lake, examined qualitatively by T. M. Chatard, contained carbonates and chlorides of sodium and potassium, with traces of sulphates, phosphates, and calcium.

### UTAH LAKE, UTAH.

Analysis by F. W. Clarke.

[Total solids: 0.3060 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0100 | 3.27 | $SiO_2$ | .0100 |
| $SO_4$ | .1306 | 42.68 | NaCl | .0204 |
| Cl | .0124 | 4.04 | $Na_2CO_3$ | .0204 |
| Ca | .0558 | 18.24 | $CaSO_4$ | .1849 |
| Mg | .0186 | 6.08 | $CaCO_3$ | .0038 |
| Na | .0178 | 5.81 | $MgCO_3$ | .0644 |
| | .2452 | | | .3039 |
| $CO_3$ | .0608 | 19.88 | 99.31 per cent accounted for. | |
| | .3060 | 100.00 | | |

A little potassium is present, but was not separately estimated.

### CITY CREEK, UTAH.

Water collected above the reservoir which supplies Salt Lake City. Analysis by T. M. Chatard.

[Total solids: 0.2400 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0090 | 3.69 | $SiO_2$ | .0090 |
| $Al_2O_3$ | .0010 | 0.41 | $Al_2O_3$ | .0010 |
| $SO_4$ | .0070 | 2.87 | NaCl | .0216 |
| Cl | .0131 | 5.38 | $Na_2CO_3$ | .0014 |
| Ca | .0589 | 24.19 | $CaSO_4$ | .0099 |
| Mg | .0174 | 7.15 | $CaCO_3$ | .1400 |
| Na | .0091 | 3.74 | $MgCO_3$ | .0606 |
| | .1155 | | | .2435 |
| $CO_3$ | .1245 | 52.57 | Total, 101.45 per cent. | |
| | .2400 | 100.00 | | |

BEAR RIVER, UTAH.

Analysis by F. W. Clarke.

[Total solids: 0.1845 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0070 | 3.79 | $SiO_2$ | .0070 |
| $SO_4$ | .0105 | 5.69 | NaCl | .0081 |
| Cl | 0049 | 2.65 | $Na_2SO_4$ | .0155 |
| Ca | .0432 | 23.41 | $CaCO_3$ | .1080 |
| Mg | .0125 | 6.78 | $MgCO_3$ | .0438 |
| Na | .0082 | 4.44 | | .1824 |
| | .0863 | | 98.86 per cent accounted for. | |
| $CO_3$ | .0982 | 53.24 | | |
| | .1845 | 100.00 | | |

UTAH HOT SPRINGS, EIGHT MILES N. OF OGDEN, UTAH.

Water received through the Smithsonian Institution. Reported temperature 55°. Analysis by F. W. Clarke.

[Total solids: 23.1150 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.0460 | 0.20 | $SiO_2$ | 0.0460 |
| $Al_2O_3$ | 0.0040 | 0.02 | $Al_2O_3$ | 0.0040 |
| $SO_4$ | 0.2184 | 0.94 | KCl | 1.6732 |
| Cl | 13.7030 | 59.28 | NaCl | 18.0168 |
| Br | trace. | ..... | $CaCl_2$ | 2.9187 |
| $CO_3$ | undet. | ..... | $MgCl_2$ | 0.1398 |
| Ca | 1.1428 | 4.83 | $CaSO_4$ | 0.3094 |
| Mg | 0.0929 | 0.40 | $MgCO_3$ | 0.2016 |
| Na | 7.0825 | 30.64 | | 23.3095 |
| K | 0.8759 | 3.79 | Total, 100.84 per cent. | |
| Li | trace. | | | |
| | 23.1655 | 100.10 | | |

The $CO_3$ in the last column, having been proved to be present, was computed to satisfy the excess of magnesium after the other acids had all been balanced. The water as received contained no iron in solution, but held an abundant ferruginous deposit.

### LIVINGSTON WARM SPRINGS, MONTANA.

Water received from A. C. Peale. Analysis by F. W. Clarke. Free $H_2S$ present.

[Total solids: 0.7575 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0290 | 3.83 | $SiO_2$ | .0290 |
| $SO_4$ | .2224 | 29.37 | KCl | .0078 |
| Cl | .0124 | 1.64 | NaCl | .0143 |
| Ca | .1678 | 22.11 | $Na_2CO_3$ | .0461 |
| Mg | .0438 | 5.79 | $CaCO_3$ | .1880 |
| Na | .0256 | 3.38 | $CaSO_4$ | .3150 |
| K | .0041 | 0.55 | $MgCO_3$ | .1533 |
| | .5051 | | | .7535 |
| $CO_2$ | .2524 | 33.33 | 99.47 per cent. accounted for. | |
| | .7575 | 100.00 | | |

### WARM SPRINGS OF EMIGRANT GULCH, YELLOWSTONE VALLEY, MONTANA.

Water received from A. C. Peale. Analysis by F. W. Clarke.

[Total solids: 0.2350 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0317 | 13.49 | $SiO_2$ | .0317 |
| $SO_4$ | .0329 | 14.00 | KCl | .0083 |
| Cl | .0074 | 3.15 | NaCl | .0058 |
| Ca | .0346 | 14.72 | $Na_2SO_4$ | .0487 |
| Mg | .0077 | 3.28 | $Na_2CO_3$ | .0274 |
| Na | .0299 | 12.72 | $CaCO_3$ | .0865 |
| K | .0043 | 1.83 | $MgCO_3$ | .0269 |
| | .1485 | | | .2353 |
| $CO_2$ | .0865 | 36.81 | Total, 100.13 per cent. | |
| | .2350 | 100.00 | | |

HELENA HOT SPRINGS, HELENA, MONT.

Water received from A. C. Peale. Reported temperature, 60.5°. Analysis by F. W. Clarke.

[Total solids: 0.6225 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0938 | 15.06 | $SiO_2$ | .0938 |
| $SO_4$ | .1854 | 29.78 | NaCl | .0596 |
| Cl | .0362 | 5.82 | $Na_2CO_3$ | .1730 |
| Ca | .0107 | 1.72 | $CaCO_3$ | .0268 |
| Mg | trace. | | $Na_2SO_4$ | .2742 |
| Na | .1873 | 30.09 | | .6274 |
| K | trace. | | | |
| Li | trace. | | Total, 100.79 per cent. | |
| | .5134 | | | |
| $CO_3$ | .1091 | 17.53 | | |
| | .6225 | 100.00 | | |

MILL CREEK COLD SPRING, YELLOWSTONE VALLEY, MONTANA.

Water received from A. C. Peale. Highly effervescent. Reported temperature, 4.5°. Analysis by F. W. Clarke.

[Total solids: 3.8125 grammes to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | 0.0250 | 0.66 | $SiO_2$ | 0.0250 |
| $Al_2O_3$. $Fe_2O_3$ | 0.0875 | 2.29 | KCl | 0.0981 |
| $SO_4$ | 0.6500 | 17.05 | NaCl | 0.3795 |
| Cl | 0.2771 | 7.27 | $Na_2SO_4$ | 0.9402 |
| I | trace. | | $Na_2CO_3$ | 0.9853 |
| Ca | 0.3768 | 9.88 | $MgCO_3$ | 0.2838 |
| Mg | 0.0811 | 2.13 | $FeCO_3$ | 0.1268 |
| Na | 0.8814 | 23.12 | $CaCO_3$ | 0.9270 |
| K | 0.0513 | 1.34 | $CaSO_4$ | 0.0204 |
| Li | trace. | | | 3.7861 |
| | 2.4302 | | 99.31 per cent. accounted for. | |
| $CO_3$ | 1.3823 | 36.26 | | |
| | 3.8125 | 100.00 | | |

In this analysis the amount of available material was insufficient. The iron in the third column is made to include the trifling quantity of aluminum which, though present, could not be separately estimated; and the calcium sulphate was directly determined as such in the insoluble residue left upon evaporating the water to dryness. The carbonates in the original water are all undoubtedly bicarbonates, and, reckoned as such, should receive the following weights: Sodium bicarbonate, 1.5618; calcium bicarbonate, 1.5017; magnesium bicarbonate, .4932; *ferrous* bicarbonate, .1945.

## VIRGINIA HOT SPRINGS, BATH COUNTY, VIRGINIA.

The waters of six different springs were received from the Virginia Hot Springs Company, as follows:

A. Boiler bath. Temperature, 41° C.

B. Hot spout bath. Temperature, 40°.5 C.

C. Octagon bath. Temperature, 38° C.

D. New hot spring. Temperature, 37° C.

E. "Sulphur" bath. Temperature, 36°.5 C.

F. "Magnesian" spring. Temperature, 25°.5 C.

Analyses by F. W. Clarke. Traces of bromine were found in A and B. The other waters were so similar to these that bromine was not specially sought for in them.

### A.—*Boiler bath.*

[Total solids: 0.5975 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0275 | 4.60 | $SiO_2$ | .0275 |
| $SO_4$ | .1319 | 22.07 | $Al_2O_3$ | .0020 |
| Cl | .0050 | 0.83 | KCl | .0105 |
| $Al_2O_3$ | .0020 | 0.32 | $K_2SO_4$ | .0128 |
| Ca | .1356 | 22.69 | $Na_2SO_4$ | .0370 |
| Mg | .0287 | 5.96 | $CaSO_4$ | .1407 |
| Na | .0120 | 2.08 | $CaCO_3$ | .2355 |
| K | .0117 | 1.96 | $MgCO_3$ | .1249 |
| | .3614 | | | .5919 |
| $CO_2$ | .2361 | 39.50 | 99.06 per cent. accounted for. | |
| | .5975 | 100.00 | | |

### B.—*Hot spout bath.*

[Total solids: 0.5925 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0235 | 3.97 | $SiO_2$ | .0235 |
| $SO_4$ | .1298 | 21.91 | $Al_2O_3$ | .0025 |
| Cl | .0044 | 0.74 | KCl | .0092 |
| $Al_2O_3$ | .0025 | 0.42 | $K_2SO_4$ | .0187 |
| Ca | .1375 | 23.21 | $Na_2SO_4$ | .0281 |
| Mg | .0343 | 5.79 | $CaSO_4$ | .1424 |
| Na | .0091 | 1.53 | $CaCO_3$ | .2390 |
| K | .0132 | 2.23 | $MgCO_3$ | .1201 |
| | .3543 | | | .5835 |
| $CO_2$ | .2382 | 40.20 | 98.46 per cent. accounted for. | |
| | .5925 | 100.00 | | |

C.—*Octagon bath.*

[Total solids: 0.5940 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0255 | 4.29 | $SiO_2$ | .0255 |
| $SO_4$ | .1364 | 22.96 | $Al_2O_3$ | .0035 |
| Cl | .0041 | 0.69 | KCl | .0066 |
| $Al_2O_3$ | .0035 | 0.59 | $K_2SO_4$ | .0185 |
| Ca | .1378 | 23.20 | $Na_2SO_4$ | .0296 |
| Mg | .0348 | 5.86 | $CaSO_4$ | .1504 |
| Na | .0096 | 1.61 | $CaCO_3$ | .2340 |
| K | .0128 | 2.15 | $MgCO_3$ | .1218 |
| | .3645 | | | .5919 |
| $CO_2$ | .2295 | 38.65 | 99.64 per cent. accounted for. | |
| | .5940 | 100.00 | | |

D.—*New hot spring.*

[Total solids: 0.5740 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0235 | 4.09 | $SiO_2$ | .0235 |
| $SO_4$ | .1294 | 22.54 | $Al_2O_3$ | .0060 |
| Cl | .0029 | 0.50 | KCl | .0061 |
| $Al_2O_3$ | .0060 | 1.04 | $K_2SO_4$ | .0212 |
| Ca | .1329 | 23.15 | $Na_2SO_4$ | .0278 |
| Mg | .0351 | 6.13 | $CaSO_4$ | .1401 |
| Na | .0090 | 1.57 | $CaCO_3$ | .2272 |
| K | .0127 | 2.21 | $MgCO_3$ | .1228 |
| | .3515 | | | .5747 |
| $CO_2$ | .2225 | 38.77 | Total, 100.12 per cent. | |
| | .5740 | 100.00 | | |

E.—*"Sulphur" bath.*

[Total solids: 0.5775 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0230 | 3.98 | $SiO_2$ | .0230 |
| $SO_4$ | .1273 | 22.04 | $Al_2O_3$ | .0065 |
| Cl | .0032 | 0.55 | KCl | .0068 |
| $Al_2O_3$ | .0065 | 1.13 | $K_2SO_4$ | .0158 |
| Ca | .1318 | 22.82 | $Na_2SO_4$ | .0420 |
| Mg | .0330 | 5.71 | $CaSO_4$ | .1278 |
| Na | .0136 | 2.36 | $CaCO_3$ | .2355 |
| K | .0107 | 1.85 | $MgCO_3$ | .1155 |
| | .3491 | | | .5729 |
| $CO_2$ | .2284 | 39.56 | 99.20 per cent. accounted for. | |
| | .5775 | 100.00 | | |

No $H_2S$ nor sulphides were found in this water. The spring, however, is said to have at times a "sulphur odor."

F.—*Magnesian spring.*

[Total solids; 0.3825 gramme to the liter.]

| Found. | | Per cent. of total solids. | Probable combination. | |
|---|---|---|---|---|
| $SiO_2$ | .0120 | 3.14 | $SiO_2$ | .0120 |
| $O_4$ | .0721 | 18.85 | KCl | .0042 |
| Cl | .0020 | 0.52 | $K_2SO_4$ | .0109 |
| Ca | .0957 | 25.02 | $Na_2SO_4$ | .0201 |
| Mg | .0209 | 5.46 | $CaSO_4$ | .0744 |
| Na | .0065 | 1.70 | $CaCO_3$ | .1345 |
| K | .0071 | 1.85 | $MgCO_3$ | .0731 |
| | .2163 | | | .3792 |
| $CO_2$ | .1662 | 43.46 | 99.14 per cent. accounted for. | |
| | .3825 | 100.00 | | |

Why this spring is specially named "Magnesian" is not explained. It will be noted that this spring, the coolest of the series, is proportionally richer in carbonates and poorer in sulphates than the others. This relation is shown by a comparison of the percentage columns.

Walter Hempel proposed (Fres. Zschr. 1881, p. 496) bismuth subnitrate as a means of decomposing silicates containing alkalies, and recommended the use of 20 parts of this salt (=10 parts of bismuth oxide) to one part of the silicate. In the Berichte d. D. Chem. Gesellsch, 1881, there is an abstract of his paper, in which is proposed the use of bismuth oxide directly.

This process has been in use in this laboratory for the past six months, and, with some modifications, has given great satisfaction. Bismuth oxide has been used instead of the subnitrate, and experience has shown that, instead of ten parts, as stated above, *two parts* of oxide to *one part* of the mineral are ample in every case in which we have employed the method.

The oxide and mineral, both finely powdered, must be most thoroughly mixed, and then heated in a platinum crucible; applying at first a gentle heat and gradually increasing to full redness, which is kept up ten to fifteen minutes. In the case of an acid silicate, complete fusion may result, while the more basic the silicate the less fusible the mixture will be. Complete decomposition has been obtained when the resulting mass was so slightly sintered together as to fall on gentle pressure into powder, none of which adhered to the crucible. It has therefore been found advantageous, in dealing with acid silicates, to add to the mixture a quantity of calcium carbonate, in weight equal to that of the mineral. This device prevents the fusion which might hinder the after treatment with acid.

After the mass has been thoroughly heated to bright redness it is allowed to cool, placed in a dish, and hydrochloric acid somewhat diluted poured over it. On heating over the water bath the mass should go into solution rapidly, leaving no residue of undecomposed mineral, which is easily distinguishble from floating flakes of silica.

If complete analysis is required, evaporate to dryness and separate the silica, as in a soda fusion, afterwards removing the bismuth by sulphureted hydrogen. If only alkalies are to be determined, add ammonia and ammonium carbonate, filter, and separate magnesia from the alkalies by any of the usual methods.

The results of this process have been very satisfactory. Out of a large number of analyses the following duplicate has been selected as being sufficient to show the accuracy of the work. It may be remarked that in the case of this margarite (a very basic silicate) the mass was but slightly sintered together.

*Margarite.—Gainesville, Ga.*

1.0300 grammes gave 0.0440 alkali chlorides = 0.0233 $Na_2O$ = 2.26 per cent.
1.0243 grammes gave 0.0435 alkali chlorides = 0.0231 $Na_2O$ = 2.25 per cent.

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# ADVERTISEMENT.

(Bulletin No. 10.)

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The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classifications of the lands and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

That whenever any document or report shall be ordered printed by Congress, there shall be printed in addition to the number in each case stated, the "usual number" [1,900] of copies for binding and distribution among those entitled to receive them.

Under these general laws it will be seen that none of the survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the annual report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the second, third, fourth, and fifth annual reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Williams's Mineral Resources, the survey has no copies of any of its publications for gratuitous distribution.

## ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

## MONOGRAPHS.

So far as already determined upon, the list of the Monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. Published.

IV. Comstock Mining and Miners, by Eliot Lord. Published.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. Published.

VI. Older Mesozoic Flora of Virginia, by Prof. Wm. M. Fontaine. Published.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. Published.

VIII. Paleontology of the Eureka District, Nevada, by Charles D. Walcott. In press.

IX. Brachiopoda and Lamellibranchiata of the Green Marls and Clays of New Jersey, by R. P Whitfield.

UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL DIRECTOR

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ON

# THE CAMBRIAN FAUNAS

OF

# NORTH AMERICA

## PRELIMINARY STUDIES

BY

CHARLES DOOLITTLE WALCOTT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
*Washington D. C., July* 1, 1884.

SIR: Herewith I have the honor to transmit the first of my preliminary studies on the Cambrian Faunas of North America.

The faunas studied are under discussion at the present time, and an early publication is desirable.

Very respectfully,

CHARLES D. WALCOTT.

Hon. J. W. POWELL,
*Director U. S. Geological Survey.*

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# ON THE CAMBRIAN FAUNAS OF NORTH AMERICA.

## PRELIMINARY STUDIES.

By CHARLES D. WALCOTT.

### REVIEW OF THE FAUNA OF THE SAINT JOHN FORMATION CONTAINED IN THE HARTT COLLECTION AT CORNELL UNIVERSITY.[1]

During the summer of 1877 the writer visited Saint John, N. B., and taking advantage of information kindly given by Mr. G. F. Mat-

[1] The term "Saint John Group" was first proposed in 1865 (Observations on the Geology of Southern New Brunswick, Fredericton, N. B., pp. 26–32) by Messrs. L. W. Bailey, G. F. Matthew, and C. F. Hartt. Subsequently, Mr. J. W. Dawson (Acad. Geol., 2nd ed., p. 638, 1868) proposed to substitute the name Acadian for the same formation. He says: "This formation has as yet been known as the Saint John Group; but I think this name unsuitable, both on account of the number of places known as Saint John, and on account of the variety of formations occurring near Saint John, in New Brunswick, and would therefore propose for the group now under consideration, characterized by Paradoxides, Conocephalites, &c., and the oldest known member of the Palæozoic of America, the name Acadian Group, by which I hope it will be known to geologists in whatever part of America it may be recognized."

The geographic area bearing the name of Acadia is defined by Mr. Dawson (*Ibid.*, p. 5) as "distinguished from all the neighboring parts of America by the enormous and remarkable development within it of rocks of the Carboniferous and Triassic systems." This certainly renders the name inapplicable as a substitute for a well-defined local name previously given to the formation under consideration.

Saint John, N. B., is quite as well known as Trenton, New York, from which the well-known Trenton limestone is named. We would not give as a reason for changing that name that other towns in the United States bear the name of Trenton.

Mr. Matthew, in speaking of the Saint John formation, says (Trans. Roy. Soc. Canada, vol. i, p. 87, 1882): "From these repor s and from the map it will be seen that the strata of the Saint John Group fill a number of narrow, trough-like basins lying between the Bay of Fundy and the central Carboniferous area of New Brunswick. Of these basins, that on which the city of Saint John is situated is the most important, and it is here, also that the life of the period can be studied to the best advantage. The Saint John basin lies diagonally across the ridges of Huronian rock that are found in the eastern part of Saint John County; and touches the ridge of Laurentian rocks that divides this county from Kings."

I cannot but think that if we pay attention to the law of priority, justice to the original discoverers of this group requires that the name of Saint John formation should be used as expressing the division of the Lower Cambrian, so well developed at Saint John.

The name Saint John or Acadian cannot well be applied to the Newfoundland or Braintree Paradoxides beds. The three localities present local differences and characters which, while permitting their being united under the general term Lower Cambrian, render it necessary to use a local name for the formation in each of the widely-separated localities.

thew, obtained a large collection of fossils from the typical localities at Saint John, Ratcliff's Millstream, and Portland, from which Mr. C. F. Hartt procured the collection described by him in the second edition of Dawson's Acadian Geology. Subsequently when working over the material, it was with great difficulty that more than the common species could be identified from the descriptions, and few figures given in the Acadian Geology. The writer at that time formed the plan of illustrating the original typical Hartt collection and also the entire fauna, as far as possible. His own collection afterward went to the Museum of Comparative Zoölogy at Cambridge, Mass., and it was not until the latter part of 1883 that the trustees of Cornell University came in possession of the Hartt collection. Through the co-operation of Mr. H. S. Williams, paleontologist of the university, the loan of the collection was obtained for the purpose of illustrating the type specimens and such other material as would add to our knowledge of the fauna. In writing to Mr. L. W. Bailey, of Fredericton, N. B., and Mr. G. F. Matthew, to secure their co-operation, the writer learned for the first time that Mr. Matthew was engaged on a monograph of the fauna of the Saint John formation. The plan of illustrating the entire fauna was at once changed so as to include only the Hartt collection, and Mr. Matthew was requested to propose specific names for the new species with the exception of one form with which the writer wished to connect the names of Mr. Hartt and Mr. Matthew, the two gentlemen who first gave to the scientific world a definite knowledge of this early Cambrian group. Mr. Matthew kindly accepted this proposal, and the writer proceeded with the work, using only the material contained in the Hartt collection.

Mr. Matthew's valuable paper on the genus Paradoxides of the Saint John Group, has already appeared (Trans. Roy. Soc. Canada, vol. i, 1882), and from it we learn that he recognizes three well-defined species and six varieties: *Paradoxides lamellatus*, Hartt; *P. lamellatus*, var. *Loricatus*, Matthew; *P. Acadicus*, Matthew; *P. Eteminicus*, Matthew; *P. Eteminicus*, vars. *suricoides*, *breviatus*, *Quacoensis*, *Malicitus* and *pontificalis*.

In the Hartt collection we find as the types of *P. lamellatus* a portion of the head of two specimens. The species appears to be of rare occurrence. Mr. Matthew illustrates but a fragment of the head of a specimen which he considers as indicating a variety of *P. lamellatus*.

Two other species occur in the collection that were not named by Mr. Hartt. *P. Acadicus*, Matt., is represented by the larger portion of an entire individual, and *P. Eteminicus*, Matt., by numerous fragments of the head. The *P. Micmac*, figured by Mr. Dawson (Acad. Geol. 2d ed., p. 657), is not represented in the collection, and Mr. Matthew writes me that the original specimens were destroyed in the great Saint John fire of 1877, and that he is unable to identify the species. The figure is a restoration, and no description accompanies it; on this account it ap-

pears best to drop the name from the list of species composing the Saint John fauna, as an undefined and undetermined species.

In reviewing the fauna as shown in the Hartt collection, we find the Echinodermata represented by single detached plates of one species, *Eocystites primævus*, Bill. A somewhat similar form occurs in the Menevian group of Wales, under the name of *Protocystites Menevensis*, Hicks.

Among the Brachiopods, *Lingula? Dawsoni*, Matt., *Acrothele Matthewi*, Hartt, *Obolella transversa*, Hartt., *Obolella*, sp., *Orthis Billingsi*, Hartt, and *Orthis*, sp. ?, show how rich and varied this class must have been at the time of the deposition of the Saint John formation.

The new type representing the Gasteropoda, *Harttia Matthewi*, is of special interest owing to its being the oldest representative of the class known on the North American continent, and the section of the family which it approaches most nearly is doubtfully known, if at all, below the Tertiary system. The species *Palæacmea? Acadica*, is as yet doubtfully referred to the gasteropoda.

Of the Pteropoda there are three species, *Hyolithes Acadica*, Hartt, *H. Danianus*, Matt., and *H. Micmac*, Matt. The former is not unlike *H. primordialis*, Hall (Sixteenth Ann. Rep. N. Y. State Cab. Nat. Hist., p. 135*), of the Potsdam sandstone of Wisconsin, and the second approaches *H. cinctus*, Barr. (Syst. Sil. Bohême, vol. iii, p. 78), of the Cambrian[2] of Bohemia.

The class Pœcilopoda, order Trilobita, is the dominant type in the Saint John fauna, as it is in all the known Cambrian faunas, and is represented by *Agnostus Acadicus*, Hartt; *Microdiscus Dawsoni*, Hartt, *M. punctatus*, Hartt; *Paradoxides lamellatus*, Hartt, *P. Acadicus*, Matt., *P. Eteminicus*, Matt.; and varieties *suricoides*, *breviatus*, *Malicitus*, *pontificalis* and *Quacoensis*; *Conocoryphe Matthewi*, Hartt, *C. elegans*, Hartt, *C. Walcotti*, Matt., *C.* (*Salteria*) *Baileyi*, Hartt; *Ptychoparia Robbi*, Hartt, *P. Ouangondiana*, Hartt, and variety *Aurora*; *P. quadrata*, Hartt, *P. Orestes*, Hartt, and varie'y *Thersites*, and *P. tener*, Hartt.

Mr. Hartt, described, in addition to these, *Conocephalites gemini-spinosus* = *Conocoryphe Matthewi*; *Conocephalites formosus* = *Ptychoparia Robbi*; *Conocephalites Aurora* = *Ptychoparia Ouangondiana*, variety *Aurora*; *Conocephalites Halli* = *Ptychoparia Orestes*; *Conocephalites Thersites* = *Ptychoparia Orestes*, variety *Thersites*; *Conocephalites neglectus* = *Ptychoparia tener*. It is with great reluctance that I reduce the above-named species to varieties and synonyms of other species, and it was not until after many comparisons and a study of all the material in the collection that it was done. Good figures are given of the types of each of Mr. Hartt's species, and the student has before him the original descriptions, so that he can judge for himself and not entirely rely upon the writer to form his opinion of the value of the species.

[2] The Cambrian system, as referred to in this paper, is that series of strata characterized by the first fauna of Barrande.

In review we find 14 genera, 26 species, and 6 varieties, distributed as follows: Echinodermata, 1 genus, 1 species; Brachiopoda, 5 genera, 7 species; Gasteropoda, 1 genus, 1 species; Pteropoda, 1 genus, 3 species; Trilobita, 6 genera, 14 species, 6 varieties.

That Mr. Matthew's researches will increase this number of species there is little doubt, and it is not improbable that some of the species of Mr. Hartt which are placed in this paper as synonyms of some others may yet prove to be distinct.

Mr. Matthew states (Trans. Roy. Soc. Canada, vol. i, p. 89) that among the collections made by the Canadian Geological Survey in New Brunswick, Mr. Billings recognized fragments of the genera Elliptocephalus and Salterella, and the remains of two species of Hyolithes. "Besides these, there are the supposed plant remains, Palæophycus, Eophyton, etc., of the higher divisions of the Saint John Group."

While studying the species, the question of their correct generic reference came up, and a number of species of three different genera were found to be arranged under the genus Conocephalites, a genus that, with the greatest respect for the opinion of its author and his work, I cannot see the way clear to accept. The reasons for this will be found under remarks on the genus Ptychoparia. The new subgenus Salteria may be of doubtful subgeneric value, but with the characters of *C.* (*Salteria*) *venulosa*, Salter, before us, a subgeneric group, appears to be indicated.

The fauna of the Saint John Group has been most happily compared by authors with that of the Paradoxides fauna of Bohemia, Wales, and Sweden. The resemblance to that of the Menevian of Wales is very striking, and the relationship so close that we are in doubt if there are not more identical species than *Microdiscus punctatus* in the two faunas.

The more closely related species are:

| Saint John. | Menevian. |
|---|---|
| Obolella transversa | Obolella sagittalis. |
| Agnostus Acadicus | Agnostus Cambrensis. |
| Microdiscus punctatus | Microdiscus punctatus. |
| Conocoryphe Matthewi | Conocoryphe Solvensis. |
| Conocoryphe elegans | Conocoryphe bufo. |
| C. (Salteria) Baileyi | C. (Salteria) venulosa. |
| Ptychoparia Robbi | Ptychoparia applanata. |

A comparison with the Swedish Paradoxides fauna gives:

| Saint John. | Swedish. |
|---|---|
| Obolella transversa | Obolella sagittalis. |
| Agnostus Acadicus | Agnostus brevifrons. |
| Conocoryphe Matthewi | Conocoryphe exsulans. |
| Conocoryphe elegans | Conocoryphe Dalmani. |
| Ptychoparia Robbi | Ptychoparia cristata. |

With the Bohemian Paradoxides fauna:

| SAINT JOHN. | BOHEMIAN. |
|---|---|
| Agnostus Acadicus | Agnostus integer. |
| Hyolithes Danianus | Hyolithes cinctus. |
| Conocoryphe Matthewi | Conocoryphe coronatus. |
| Conocoryphe elegans | Conocoryphe Sulzeri. |
| Ptychoparia Robbi | Ptychoparia Emmrichi. |

Mr. Matthew calls attention to the close interrelationship of the species of the Saint John Paradoxides and to the fact that they belong to a group characterized by a continuous eye-lobe, a feature developed in *Paradoxides rugulosus*, Corda (Syst. Sil. Bohême., vol. i, p. 374), of Bohemia. In the genus Anopolenus (Quar. Jour. Geol. Soc., vol. xxi, p. 177) the eye-lobes are continuous, but of a different character from the Saint John Paradoxides. *Olenellus asaphoides* (Amer. Jour. Sci., vol. xiii, p. 265) shows a continuous eye-lobe in some of the younger stages of development, a character not retained in the adult individual.

In comparing the Saint John fauna of Saint John with that of other localities of the Saint John fauna in North America, the first to be noted is that of Manuel's Brook, near Conception Bay, Newfoundland, as described by Mr. J. F. Whiteaves (Amer. Jour. Sci., 3d ser., vol. xvi, p. 224, 1878).

Mr. Whiteaves identifies of the Saint John fauna: *Agnostus Acadicus*, *Microdiscus Dawsoni*, *Microdiscus punctatus*, *Paradoxides*, sp. ?, *C.* (*Salteria*) *Baileyi*, *Ptychoparia tener*, *Ptychoparia Orestes* ?.

On the authority of Mr. Alex. Murray, the shales containing this fauna are considered by Mr. Whiteaves as lower than the strata from which Mr. Billings obtained a strongly-marked Cambrian fauna that he refers to the Menevian Group (Can. Nat., 2d ser., vol. vi, p. 470, 1872).

From this horizon Mr. Billings described *Obolella? miser*, *Straparollina remota*, *Hyolithes excellens*, *Paradoxides tenellus*, *Paradoxides decorus*, *P.* (*Anopolenus*) *venustus*, *Agraulos affinis*, *A. socialis*, *A. strenuus*, *Ptychoparia* (*Solenopleura*) *communis*.

Mr. Billings also describes *Stenotheca pauper* and *Scenella reticulata*, from Conception Bay, the stratigraphic horizon being a little above the Manuel's Brook shales containing the Saint John fauna. To these we have to add the large *Paradoxides Bennetti*, Salter (Quart. Journ. Geol. Soc., vol. xv, p. 552, 1859), and *Bathyurus*=*Solenopleura gregaria*, Billings (Pal. Foss., vol. i, p. 363, 1865), from the Paradoxides slates of Saint Mary's Bay, Newfoundland, which gives a total of fourteen described species from Paradoxides beds above the Saint John fauna.

From the sections given by Mr. Murray (Geol. Surv. Newfoundland, p. 157, 1881), we learn that the shales carrying the Saint John fauna are the lowest fossiliferous strata in Newfoundland, and that the Paradoxides beds above carry a fauna unlike the Saint John fauna. This proves the latter fauna to be the oldest known on the American continent, and when compared to the older Cambrian faunas of Wales, to

be low down in the Menevian if not representative of that of portions of the Harlech and Longmynd groups.

Near Saint John, N. B., there is a commingling of representative species that are distributed in the St. David's section of Wales, from the Harlech to the Upper Menevian, a fact that tells us plainly that we need not look for a close similarity in the succession of individual species in sections of the same relative geologic position when widely separated. The physical conditions of environment and the geographic distribution of species tend to variation in the assemblage of forms at localities but slightly separated, and still more when widely distant from each other.

In the Braintree argillites there are four species, *Hyolithes Shaleri*, Walcott (this bulletin), *Paradoxides Harlani*, Green (Amer. Journ. Sci., vol. xxv, p. 336, 1834), *Ptychoparia Rogersi*, Walcott (this bulletin), and *Agraulos quadrangularis*, Whitfield (Bull. Amer. Mus. Nat. Hist., vol. i, p. 147, 1884).

*Hyolithes Shaleri* is closely allied to *Hyolithes excellens*, Billings (Pal. Foss., vol. ii, pt. 1, p. 70, 1874).

The *Paradoxides Harlani* is of the type of *Paradoxides Bennetti*, of Newfoundland, as found above the Saint John fauna, and corresponds to the Bohemian group of the genus typified by *P. spinosus*, Boeck, and the Menevian *P. Hicksii*, Salter. *Agraulos quadrangularis*, Whitfield, is a type present in the Paradoxides horizon in Newfoundland, as *A. socialis*, *A. strenuus*, and *A. affinis*, Billings (Pal. Foss., vol. ii, pt. 1, p. 71), in the Menevian of Wales, as *A. longicephalus*, Hicks (Quar. Jour. Geol. Soc., vol. xxviii, p. 176), in Bohemia, as *A. ceticephalus*, Barrande (Syst. Sil. Bohême., vol. i, p. 405). *Ptychoparia Rogersi* is more of the type of *Ptychoparia Emmrichi*, Barrande, of Bohemia.

Up to the present time no other localities of the Paradoxides fauna have been discovered in North America.

The relations of the Saint John fauna to the remaining portion of the Paradoxides fauna in Newfoundland we have mentioned, but as yet no section has shown the connection of the Paradoxides fauna with that of the next superior or Georgian fauna. As I am engaged on a review of the latter fauna, the discussion will be omitted here to appear in a paper on that portion of the Cambrian fauna.

## Genus EOCYSTITES, Billings.

### EOCYSTITES PRIMÆVUS, Billings.

Plate i, fig. 2.

*Eocystites primævus*, Billings, 1868, Acadian Geology, Dawson, 2d ed., p. 643.

No description accompanies the illustration of the single plate of this form, and, in fact, little can be said of it from the material in the collection.

The plates are polygonal in outline, variable in size and form, elevated at the center, and ornamented by 9, 10, or 11 principal ridges radiating from the center with smaller ridges coming in between the larger ones, usually showing a pentagonal arrangement. The plates vary from 3 to 5 millimeters in diameter. It is quite probable that a new generic form is indicated, but in its relations to other genera nothing can be determined. *Protocystites Menevensis*, Hicks, evidently belongs to a similar type, if not to the same genus.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B.

## Genus LINGULA, Bruguière.

### LINGULA ? DAWSONI, Matthew.

Plate v, fig. 8.

*Lingula ? Dawsoni*, Matthew, 1884. MSS.

Shell small, broadly subelliptical, subattenuate towards the beak; margins gradually expanding and curving from the beak to the center, where the shell has its greatest width, and thence narrowing towards the front, which is broadly rounded. General surface depressed convex, becoming more convex towards the beak.

Surface marked by fine undulating concentric lines crossed by radiating lines that are seen only by the aid of a strong magnifying glass.

In form this species approaches *Lingulella ferruginea*, Salter (See Man. Brit. Foss. Brach., Davidson, vol. iii, p. 336), of the Menevian formation of Wales quite closely, but with only a specimen of the ventral (?) valve to compare with it, it is difficult to satisfactorily determine its specific relations.

*Formation and locality.*—Cambrian. Saint John formation, Saint John, N. B.

The following notice of a larger shell than *Acrothele Matthewi* appears on page 644 of the Acadian Geology as a new species of Lingula:

"Lingula, n. sp., Hartt, differs from the above (*A. Matthewi*) in being almost straight in front, broadly rounded at the sides, and narrowed towards and pointed at the umbo. It was also larger, thicker, and more convex."

The original specimen I have failed to find in the collections, and no form corresponding to it has been observed.

## Genus ACROTHELE, Linnarsson.

### ACROTHELE MATTHEWI, Hartt, sp.

Plate i, figs. 4, 4a.

*Lingula Matthewi* Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 644, fig. 221.

*Description.*—"Dorsal valve, circular in outline or very slightly wider than long, extremely flat, the convexity being scarcely noticeable; shell

very thin; on each side a segment, such as would be cut off by a chord running from the umbo to the extremity of the transverse diameter, is slightly turned up on the margin.

"Inside, a strong mesial ridge, rounded and of moderate width, runs from the umbo to a point a little beyond the middle of the shell; at the umbo this ridge bears a small nailhead-like process or swelling, and there are two minute and extremely short secondary ridges, originating from the head of the primary, and extending obliquely backwards. Inner surface marked with numerous indistinct and irregular concentric striæ; outer surface not visible."

A study of the type specimen of this species, which is a cast of the interior of the dorsal valve, leads to its reference to the genus Acrothele, as it presents characters shown in a typical form of Acrothele, *A. subsidua*, White (Expl. and Surv. West 100th Merid., vol. iv, pt. 1, p. 34), from the Cambrian of Utah. On the list left by Professor Hartt, reference is made to specimen No. 342 as *Obolus (Discina) nitidus*, sp. nov. This specimen presents the characters of a ventral valve of Acrothele, and is of the form that the ventral valve of *A. Matthewi* would probably have, and although not associated with it at Saint John, I have little hesitancy in referring to it as the ventral valve of *A. Matthewi*. It is illustrated on plate i, fig. 4*a*.

*Formation and locality.*—Cambrian. Saint John formation, Saint John and Ratcliff's Millstream, N. B.

## Genus OBOLELLA, Billings.

### OBOLELLA TRANSVERSA, Hartt.

Plate i, figs. 5, 5*a*.

*Obolella transversa*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 644.)

"A very small, transversely oval species, from Coldbrook, Saint John."

The above is all the description by the author of the species and no figure is given, but, with the typical material used by him before me, there is little difficulty in recognizing the species.

It is closely allied to *Obolella sagittalis*, Salter, and Mr. Davidson's description of that species (Geol. Mag., vol. v, p. 309, 1868) reads as though it were drawn from the Saint John specimens. Figures are given of the interiors of the two valves.

*Obolella? miser*, Billings (Pal. Fos. vol. ii, pt. 1, p. 69, 1874), is a closely allied species from the Saint John formation horizon. No figures accompany the description.

*Formation and locality.*—Cambrian. Saint John formation, Coldbrook, Saint John, N. B.

### OBOLELLA, sp. undt.

What appears to be a second species occurs with the preceding. The form is more elongate, the surface is concentrically striated with fine

lines, and the interior appears to be less strongly marked by the muscular scars.

## Genus ORTHIS, Dalman.

### ORTHIS BILLINGSI, Hartt.

Plate i, figs. 1, 1*b–d*.

*Orthis Billingsi*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 644, fig. 223.

*Description.*—"Shell subquadrate to semicircular, broader than long; greatest width at the hinge-line; moderately convex; greatest thickness at about the middle; depressed in front. Hinge-line straight. Dorsal valve semicircular or subquadrate; depressed, with a shallow sinus running from the umbo to the front. Umbo not elevated above the hinge-area, which is very narrow, and marked by fine, parallel longitudinal striæ. Hinge-plate bearing two slight incurved internal processes. Ventral valve more arched than the dorsal, with a narrow, flat margin produced in the plane of the valve. Hinge-area triangular, concave, and marked with fine parallel lines. Umbo elevated above hinge-line about one-fourth of length of shell. Foramen triangular and of moderate size. Surface ornamented by about thirty prominent rounded, radiating plicæ, increasing in width towards the margin, becoming less elevated and slightly curved toward the ears, crossed by a number of distinctly marked, concentric, squamose lines of growth, and numerous fine concentric striæ. The radiating plicæ increase by bifurcation, which takes place at about one-third the distance from the umbo to the margin."

The figure accompanying the above description is that of a rather transverse ventral valve, on which the radiating costæ are unusually strong. They also bifurcate in a manner observed in but one other specimen in the collection. At first sight this shell will be separated as a distinct species from the variety, having sharp, somewhat distant ribs radiating from the beak, with finer ribs appearing between them on the cast, but other specimens occur where the two surface characters are shown on the same shell, and give the impression that we have a single variable species, the two extremes of which are shown in our figures 1, 1*d*, of plate i. The crowding together of the increased number of ribs on the costate variety gives the bifurcating character to the ribs or costæ.

The ventral valve of *O. Billingsi* is little elevated, in this respect being unlike other Cambrian species, and there does not appear to be any nearly-related species of Orthis in strata of Cambrian age. *Orthis Hicksi*, Salter (see Davidson's Mon. Brit. Foss. Brach., vol. iii, p. 230), is the prevailing form in the Menevian of Wales, and in some of

its phases resembles *O. Billingsi*. Among the Swedish forms the latter may be compared with *O. exporecta*, Linnarsson (Bihang till K. Svenska Vet. Akad. Handlingar. Band. 3, N:o. 12, p. 12, 1876).

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream and Saint John, N. B.

### ORTHIS, sp. ?

Plate i, fig. 1*a*.

Associated with the preceding at Saint John, there is a small single dorsal (?) valve of a species of Orthis that appears to be distinct from *O. Billingsi*. A moderately well-defined median sinus is shown and the surface, as preserved in the cast, was somewhat finely ribbed. Professor Hartt refers to a new species of Orthis as not being sufficiently well represented to warrant its description, but gives another specimen, fig. 1*c*, plate i, as the form. This I consider as a variety of *O. Billingsi*, and the shell under consideration may only have the same position when a larger series comes to be studied.

### Genus HARTTIA, n. gen.

This generic name is proposed for a unique little shell found in association with fragments of trilobites of the genera Paradoxides and Ptychoparia.

*Description.*—A small, oval, patelliform shell, having a low, broad ridge originating on the posterior (?) side of the interior that supports a subcordate shield-like expansion which extends out over the anterior (?) portion of the interior when we look down into the shell. The broad base of the ridge and the general character of the shield-like extension are well shown in the figure on plate i, fig. 3.

The character of the apex is unknown, as the only representation of the genus and species is in the form of a cast, showing the interior of the central portion and, around the margins, the cast of the apparently smooth outer surface.

The interior ridge and shield-like expansion is of a peculiar character, and unlike that of any described recent or fossil form known to me. It is so well marked that there is little hesitancy in proposing a new genus for its reception. The genus may be included in the Calyptræidæ nearest the genus Crepidula, if we compare the shield-like expansion with the shelf or shelly partition of Crepidula. However close or distant its relations to the latter, it certainly appears to be the representative of the Calyptræidæ type in the Cambrian, and adds another form, showing the differentiation of the invertebrate fauna in the oldest fauna yet known on the American continent.

The generic name is in honor of Mr. C. F. Hartt. With it I wish to

associate that of Mr. G. F. Matthew, the discoverer of the Cambrian age of the Saint John formation.

### HARTTIA MATTHEWI, n. sp.

Plate i, fig. 3.

The characters of this species have already been given under the description of the genus.

The base of the shell, as shown in the specimen, measures 2.5$^{mm}$ by 3.5$^{mm}$. It was probably a little larger, as the true margin is not to a certainty clearly shown.

There is no reference or record number attached to the specimen, and nothing is said of it in Mr. Hartt's notes as published by Mr. Dawson. A scratched outline around the specimen shows that it had been noticed, but whether by one of the collectors of the specimens or by Mr. Hartt is unknown.

*Formation and locality.*—Cambrian. Saint John formation. The character of the slate and the embedded fossils is similar to that of the material from Ratcliff's Millstream, and it was associated in the collection with specimens from that locality.

## Genus PALÆACMEA, H. & W.

### PALÆACMEA ? ACADICA, Hartt.

Plate i, fig. 6.

*Discina Acadica*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 644, Fig. 222..

*Description.*—"Shell elliptical in outline; sides more or less straight. Conical, but very depressed. Apex apparently central. Surface marked with a number of deep, concentric, irregular, sharp furrows, not always continuous, and often breaking up into smaller grooves, and all these seem at times to be impressed with lighter lines running nearly parallel with them. Of the large furrows from nine to ten can usually be counted. The whole surface of the shell is marked with a great number of delicate raised lines radiating from the summit to the circumference, and just visible to the naked eye."

An examination of several specimens of this species, including the types, leads me to think with Mr. R. P. Whitfield (Bull. Amer. Mus. Nat. Hist., vol. i, p. 141, 1884), that it is not a true Discina, but probably a univalve shell, allied to Palæacmea or Stenotheca. The material in the collection is very poor and fragmentary; so much so that the generic reference is to be considered as merely provisional.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B.

## Genus HYOLITHES, Eichwald.

### HYOLITHES ACADICA, Hartt.

Plate ii, fig. 5.

*Theca Acadica*, Hartt. Label on specimen.

Form an elongate triangular pyramid, tapering gradually and uniformly to an acute extremity. Transverse section subtriangular, about twice as wide as high; the lateral angles acute from compression in the specimens in the collection. Ventral face slightly arched; anterior margin extending forward in a semicircular subspatulate extension. Dorsal surface rather strongly convex. Aperture unknown, but undoubtedly oblique, judging from the character of the extension of the ventral side.

Operculum unknown.

Surface of shell marked by concentric lines of growth, parallel to the margin of the aperture, and exceedingly fine longitudinal striæ visible only by the aid of a strong magnifier.

In general form this species approaches very closely to *Hyolithes Americanus*, Billings (Can. Nat. n. ser., vol. vi, p. 215, 1872), but equally so to the Devonian *H. aclis*, Hall (Pal. N. Y., vol. v, pt. 2, p. 197,) except in the more rounded dorsal side.

Owing to the imperfect condition of preservation of the species illustrated from the Menevian group of Wales, it is difficult to make comparisons with them. Professor Hartt's specific name is retained, as the probabilities are that the form is different from the American Potsdam and Georgian species, although allied to *H. primordialis*, Hall (Sixteenth Ann. Rep. State Cab. Nat. Hist., p. 135,* 1863), and also the Menevian forms of the genus in Wales.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B.

### HYOLITHES DANIANUS, Matthews.

Plate ii, figs. 7, 7*a*, *b*.

*Hyolithes Danianus*, Matthews, 1884, MSS.

Form that of an extremely elongate rounded subtriangular pyramid that, in some examples, curves a little to one side as it becomes gradually attenuate towards the apex. Transverse section semielliptical; moderately convex on the ventral side and still more so on the dorsal. Ventral face flattened and almost concave along the center, rounding up on each side to the somewhat rounder lateral angles. Dorsal face not very strongly convex transversely. Form of aperture unknown.

Associated operculum broad oval, or subcircular in general form. The side corresponding to the ventral side of the shell curves regularly, but is not as convex as the opposite side. The umbo is situated

about four-fifths the distance from the dorsal margin, and extends laterally as a low, rounded ridge towards the rounded angles formed by the union of the ventral and dorsal sides of the operculum; just in front of these ridges a slight depression exists, also a depressed area back of the umbo, or towards the dorsal margin; the inner side shows a sharp ridge corresponding to the umbonal ridges on the outside, and also a sharp, short, elevated ridge between the ventral margin and the position of the umbo on the outer surface. The general body of the shell of the operculum appears to have been quite thin.

Surface of the shell marked by transverse, concentric undulations of growth that arch slightly forward on the ventral side. Outer surface of the operculum marked by fine concentric striæ and very fine, somewhat obscure, radiating striæ; inner surface with fine, slightly irregular, radiating lines or striæ.

There is considerable range of variation in the form of the shells of this species. In some the flattening of the ventral side is lost, and only a convex surface is shown, and the dorsal surface has a narrow longitudinal line on each side of the center. The curvature of the shell also varies considerably. A number of specimens of the operculum are associated with the shells, but none were observed attached before the mouth of the shell.

One unusually curved shell having a nearly round section, was labeled Orthoceras? n. sp., by Professor Hartt, as traces of what appear to be septa are shown. The distances between the septa-like partitions are unequal, and in other specimens this is seen to be owing to the filling of cracks across the tube.

This species recalls *Hyolithes cinctus*, Barrande (Syst. Sil. Bohême., vol. iii, plate ix, figs. 8–12), and the form of the associated operculum is also similar.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B.

### HYOLITHES MICMAC, Matthew.

Plate ii, fig. 6.

*Hyolithes Micmac*, Matthew, 1884, MSS.

Form that of an extremely elongate, rounded, subtriangular pyramid that becomes gradually attenuate towards the apex. The true transverse section is not preserved, owing to the crushing down of the shell, and appears to have been semielliptical or rounded subtriangular.

Form of aperture and operculum unknown.

Surface of the shell smooth externally; the interior is marked by fine, raised, longitudinal lines.

In form this species is not unlike *Hyolithes Danianus*, but the smooth outer surface and striated inner surface distinguishes it from that and also any other described species known to me.

Dimensions: Length of specimen 20mm, width at aperture 4mm.

*Formation and locality.*—Cambrian. Saint John formation, associated with *Microdiscus punctatus* at Ratcliff's Millstream, N. B.

## Genus AGNOSTUS, Brongniart.

### AGNOSTUS ACADICUS, Hartt.

Plate ii, figs. 2, 2*a*–*c*.

*Agnostus Acadicus*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 655.
*Agnostus similis*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 656.

*Description.*—"Head minute, transversely-elliptical, or subcircular; breadth and length about equal, convex but very depressed, outlines in front and on the sides slightly straightened. A narrow, flattened, and but very slightly elevated border goes round the front and lateral margins. This is separated from rest of shield by a narrow, shallow, flat space, or groove, which, on going posteriorly along the lateral margins, loses gradually in width toward the posterior angles of shield, which are rounded. Glabella a little less than two-thirds the length of shield, long elliptical, depressed convex, but more elevated than other parts of the shield, about twice as long as broad, bounded anteriorly and laterally by a sharp, rather deep groove concentric to the outer one above described. A well-marked transverse furrow, arching backwards, separates the anterior third of the glabella as a subcircular lobe. Posterior part of glabella rounded, but impressed on each side by a little lobe situated in the angle between the cheek-lobe and the glabella. These little lobes are about one-quarter the size of the anterior glabellar lobe. Cheeks of the same width throughout, and uniting in front of the glabella, being bounded by the two concentric grooves above mentioned. Posteriorly they are rounded; in width they are rather greater than the glabella. They are convex, more elevated along their inner margin, but sloping outward roundly and evenly. Glabella with its lobes project considerably beyond posterior margin. Surface smooth. Pygidium of this species (?) of about the same outline as cephalic shield. The posterior and lateral margins have a slight, raised border, separated from lateral lobes by a shallow but well-marked groove running parallel to the margin. This groove widens at the point where it bends to go forward along the sides in such a way as to encroach on and thin out the marginal fold, and, just before reaching the anterior margin, it narrows itself from the inner side so as to cause the lateral lobes to widen somewhat anteriorly. These are narrow, flattened, about half as wide as the middle lobe, narrowing to a point just behind the middle lobe, where they do not unite. The medial lobe is about five-sixths of length of pygidium, shield-shaped, flattened, convex, more elevated than the lateral lobe. Its anterior border is slightly concave in the middle. The lateral angles are rounded, and the lobe is contracted a little an-

teriorly. It is bounded by two deep and well-marked furrows, which join one another in the middle of the marginal furrow, forming a pointed arch. Medial lobe projecting farther forwards than the lateral ones. A little spine is situated on its mesial line about one-fourth its length from front. Surface smooth."

After a careful study of all the specimens in the collection, fifteen in number, I am unable to make out sufficient differences between the form described as *A. Acadicus* and that given as *A. similis*, to establish two species. There is a certain range of variation in the specimens as pointed out by Mr. Hartt, but that is so variable and owes its origin so largely to the condition of preservation of the various specimens that it is not evident that two species are typified.

*Agnostus Acadicus* is a type of the genus that occurs in the Menevian of Wales, as *A. Cambrensis*, Hicks (Quart. Jour. Geol. Soc., vol. xxvii, p. 400, 1871); in Norway, as *A. brevifrons*, Angelin (Pal. Scan., p. 6, 1852); in Bohemia as *A. integer*, Beyr. (Sil. Syst. Bohême., vol. i, p. 900, 1852); and in the American Potsdam horizon as *A. Neon*, Hall & Whitfield (Geol. Expl. 40th Par., vol. iv, p. 229, 1877). *Agnostus interstrictus*, White (Expl. and Surv., West 100th Merid., vol. iv, p. 38), from the Cambrian of Utah, is an almost identical species, differing principally in the postero-lateral angles of the pygidium.

*Formation and locality.*—Cambrian, Saint John formation, Saint John, N. B.

## Genus MICRODISCUS, Emmons.

### MICRODISCUS DAWSONI, Hartt.

Plate ii, figs. 3, 3*a*.

*Microdiscus Dawsoni*, Hartt, 1868. Acadian Geology, Dawson, 2d ed., p. 654.

*Description.*—"Cephalic shield semi-lunar, with thickened border crossed by numerous grooves running perpendicularly to the circumference. Glabella convex, narrow, rounded in front, conical and pointed behind, projecting beyond posterior border, without furrows or occipital groove. Cheeks convex, no eyes, and no traces of sutures. Posterior angles of shield with backward projecting spines. Pygidium subtriangular, with curved outlines, rounded in front and behind; middle lobe distinctly marked, and divided into six segments; lateral lobe also divided, furnished with a narrow border."

This is a beautiful little trilobite that is quite distinct from described species of the genus.

There are but three specimens in the collection, and none show the head and pygidium united.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B.

## MICRODISCUS PUNCTATUS, Salter.

Plate ii, figs. 1, 1*a–c*.

*Microdiscus punctatus*, Salter, 1864, Quart. Journ. Geol. Soc., vol. xx, p. 237, plate xiii, fig. 11.

*Microdiscus punctatus*, Whiteaves, 1878, Amer. Journ. Sci., 3d ser., vol. xvi, p. 225.

*Microdiscus pulchellus*, Hartt. Name proposed (No. 14) on list of fossils sent to Mr. J. W. Dawson.

Head semi-elliptical in outline, rather strongly convex, and bordered on the front and sides by a depressed furrow and raised rim, the furrow containing numerous short furrows perpendicular to the margin, as in *M. Dawsoni*, but not as strongly marked. The posterior border is strong back of the cheeks, and has the furrow continuing from the sides; a very narrow rim extends back of the glabella; eyes and facial suture entirely absent.

Glabella elongate conical, extending backward in a strong spine as long as the glabella in medium-sized specimens and nearly as broad at the base. In some examples the spine is shorter and smaller. The glabella rises above the level of the cheeks and is about three-fifths the length of the head, bordered by strong dorsal furrows that are connected in front by a straight furrow with the depressed groove within the anterior marginal border, perceptibly marked by two pairs of oblique glabellar furrows in some examples. Cheeks convex, prominent, strongly defined by the dorsal and marginal furrows.

Thorax unknown.

The pygidium, associated with the head of this species in great numbers, has the same general outline as the head. The narrow marginal rim is well defined all around, widest at the sides; anterior marginal furrow very distinct; median lobe elongate-conical, extending back nearly to the marginal groove; nine anchylosed segments are indicated by eight rather strong transverse furrows; lateral lobes strongly convex, no furrow appearing back of the anterior marginal groove.

Surface finely punctate, the punctæ being rather large as compared with the depth.

Dimensions of a rather broad head: Length, exclusive of spine, 3.5$^{mm}$; breadth, 5$^{mm}$; occipital spine, 3$^{mm}$; pygidium, length, 3.75$^{mm}$, breadth, 5$^{mm}$.

This is an abundant and well-marked species. Mr. Hartt evidently intended to describe it, as the name is given in his list, and selected specimens were mounted on blocks, one of which bears the name *Eodiscus pulchellus*, Hartt, n. g., n. sp. There is considerable variation in the relative proportion of the length and breadth of the head, also of the pygidium in different specimens, owing to an original variation, and also distortion from compression in the shales.

Mr. Whiteaves states that this species was first detected in the

Primordial slates of Saint John, N. B., by the late Mr. E. Billings It has since been observed in rocks of the same age on the Kennebecasis River, N. B., where it was collected by Mr. G. F. Matthew.

The pygidium is very similar to that of *Microdiscus speciosus*, Ford (Amer. Jour. Sci., vol. vi, p. 137, 1873).

In comparing with the figures of *M. punctatus* given by Mr. Salter, it is observed that the nuchal spine of *M. punctatus* is longer and more slender, and the surface of the cephalic shield and pygidium are punctate, whereas, in the Saint John's specimens, the surface is smooth. In event of the two forms proving distinct on a comparison of specimens, I propose that Mr. Hartt's name, *M. pulchellus*, be given to the American species.

*Formation and localities.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B., and Manuel's Brook, near Conception Bay, Newfoundland.

## Genus PARADOXIDES, Brongniart.

### PARADOXIDES LAMELLATUS, Hartt.

Plate iii, figs. 2, 2*a*.

*Paradoxides lamellatus*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 656.
*Paradoxides lamellatus*, var. *loricatus*, Matthew, 1882, Trans. Roy. Soc. Canada, p. 105. plate ix, fig. 19.

*Description.*—"This is a small species distinguished from several others found with it by the presence of a number of sharp perpendicular laminæ on the anterior lobe of the glabella."

The types of this species consist of the casts of portions of two heads, both of which are illustrated on plate iii. It is, as stated by Mr. Hartt, distinguished from the associated species by the sharp perpendicular laminæ or ridges in front of the glabella.

Mr. Matthew has indicated a variety as *P. lamellatus*, var. *loricatus*. The elevated ridges on the front of glabella are variable in the two type specimens, and I should not consider the variation cited by Mr. Matthew as of sufficient importance to establish a varietal name, especially as he suggests the idea that the transverse ridges or interrupted elevated lines owe their origin to the condensation of the frontal area by transfer to the glabella; this would necessarily induce a great variation in the form and arrangement of the elevated lines in relation to each other, although they might retain their general relation to the frontal margin.

*Formation and locality.*—Cambrian. Saint John formation, Portland, a little northward of Saint John, N. B.

### PARADOXIDES ACADICUS, Matthew.

Plate iii, fig. 3, 3*a*.

*Paradoxides Acadicus*, Matthew, 1882, Trans. Roy. Soc. Canada, p. 103, Plate ix, figs. 16–18.

Mr. Hartt recognized several species of paradoxides and indicated them in his list, but did not name or designate the specimens, owing to

his not having time to work out the details (Acadian Geol., 2d ed., p. 657, 1868). One of these Mr. Matthew, in his valuable paper on the Paradoxides, has named *P. Acadicus*, describing it as follows:

"The anterior margin is regularly rounded and strongly arched backward. The marginal fold is moderately convex and about twice as wide at the extremity as in front of the glabella. The flat area is very small, and at the suture about as wide as the marginal fold.

"The glabella is about an eighth longer than wide. It expands regularly from the base to a point somewhat in advance of the fourth furrow, whence it is regularly rounded to the front.

"The glabellar furrows are all heavily cut. The first two cross the axis of the glabella; of these the first is arched decidedly backward, and is somewhat more heavily impressed in the outer than in the middle third. The second furrow strongly indents the glabella parallel to the transverse axis; it is more lightly impressed in the middle quarter than elsewhere. The two anterior furrows are in pairs. The third fails to cross the glabella by less than a third of the glabella's width; it begins within the margin of the glabella and is directed forward at an angle of about fifteen degrees. The fourth furrow begins on the edge of the glabella, and scarcely extends one-quarter of the way across it.

"The occipital ring is more than twice as long as wide; it is regularly convex and moderately arched vertically; a little behind the middle of the ring is a short tuberculous spine. In some of the largest heads the middle half of the ring is raised into a broad, rather flat, lobe which bears the spine. The occipital furrow is more strongly impressed in the outer quarter than in the middle.

"The posterior margin is moderately arched backward; the fold is regularly convex and moderately arched vertically. The furrow is scarcely as wide as the fold, and is rounded in the bottom.

"The fixed cheek is subtrapezoidal in form, is convex, and has an elevation at the posterior inner angle; it is strongly depressed in front, and the bounding furrows are distinct. The ocular lobe makes an open parabolic curve, and is prominently raised all round, but especially at the extremities. The curve of the posterior third of the ocular lobe in this species is more open than in that of the preceding species or its varieties.

"*Sculpture.*—Parallel raised lines appear only on the front half of the marginal fold, where there are about five. Elsewhere the surface of the test is covered with closely-set granulations visible to the naked eye.

"This neat little species is easily distinguished from all the preceding by its granulated surface, and by the absence of raised lines on the front of the glabella."

In the Hartt collection there is a specimen that adds materially to our knowledge of the species and the group of species to which it belongs, as fourteen segments of the thorax, the pygidium, and a portion

of the head are preserved. The head parts appear to be identical with the typical form described by Mr. Matthew, and are ornamented by the granulated surface, characteristic of the species. The thorax is very broad in proportion to its length, even though the fourteen segments preserved are not considered as entirely forming it. The allied Bohemian type, *Paradoxides rugulosus*, Corda (Syst. Silur. de Bohême., p. 347, plates ix and xiii), has but sixteen segments and the specimen under consideration shows no traces of more than fourteen; the anterior segments, however, are crowded down somewhat, and the head pushed to one side, which leaves the question of the actual number of segments unsettled. The median lobe is crushed together, but still shows that it had a width of $7^{mm}$ or $8^{mm}$ at the twelfth segment, the pleural lobe on each side of the same segment extending out $12^{mm}$ from the median lobe and terminating in slightly curved mucronate points of the same length on all the segments; posteriorly the median and lateral lobes contract, the pleural portion of the last four segments expanding and bending back so as to close down to the side of the pygidium; the pleural grooves are well marked and extend out about half way on the pleural lobe. The pygidium is the type of that of *P. rugulosus*, (*loc. cit.*), and corresponds to figure 19 of plate x of Mr. Matthew's paper more closely than any other.

*Formation and locality.*—The locality is not given with the specimen, but Mr. Matthew cites the species from Portland, N. B., and the lithologic characters of the shale correspond to specimens from that locality.

### PARADOXIDES ETEMINICUS, Matthew.

Plate iii, figs. 1, 1*a–g*.

*Paradoxides Eteminicus*, Matthew, 1883, Trans. Roy. Soc. Canada, vol. i; p. 92, plate x, figs. 7–12.

Mr. Matthew gives a very elaborate description of this fine species and divides it into *P. Eteminicus* and four varieties, viz: *Suricoides*, *breviatus*, *Quacoensis*, *Malicitus*, and *pontificalis*, the differences separating each appearing in the glabella, fixed cheeks, and the anterior lateral limbs. From our experience with the varying forms of Olenellus from Nevada, we should scarcely consider these, on the evidence given, as more than varieties of one species, as Mr. Matthew has done. A number of specimens of this species occur in the collection. One head (sp.?) indicates a trilobite $18^{cm}$. or $20^{cm}$. in length when entire, the portion of the head remaining being $6^{cm}$. long.

For the purpose of illustrating the species of the Saint John fauna, known to me at present, several figures of *P. Eteminicus* are copied from Mr. Matthew's paper.

*Formation and localities.*—Cambrian. Saint John formation, Portland and Ratcliff's Millstream, N. B.

## Genus CONOCORYPHE, Corda.[3]

### CONOCORYPHE (Subgenus?) MATTHEWI.

Plate iv, figs. 1, 1*a*, *b*.

*Conocephalites Matthewi*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 646.
*Conocephalites gemini-spinosus*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 653.

*Description.*—"Head semi-circular to semi-elliptical, more than twice as wide as long; front and lateral margins forming a regular curve; posterior margin nearly straight; posterior angles of shield flattened and rounded without spines; margin with a strong, round, rather narrow fold, which becomes narrower and lower towards the posterior angle of shield, where it disappears. This is separated from the cheek-lobes by a very deep, moderately-broad groove. This groove is arched forward in front by a large, semi-globose swelling, situated just in advance of the glabella, encroaching upon the marginal fold, causing it to be the thickest on each side of this prominence.

"The posterior margin is also folded, but the plait is more or less inclined backwards. The fold is narrow near the occipital ring, but grows more prominent and gains in width towards the posterior angle, but, like the anterior fold, it disappears at that point. Its course is not straight; at about half the distance of the outer angle it bends slightly backwards and downwards and then forwards slightly to disappear on the flattened or rounded angle of the shield. This fold is separated from the cheek-lobes by a groove shallower and broader than the marginal one, which it resembles, by expanding gradually into the flattened space of the outer angle. This groove follows a course parallel to the fold which it accompanies. Length from occipital furrow, about half that of head.

"Glabella subconical, longer than wide, strongly rounded in front, and about half as wide anteriorly as posteriorly; length about that of whole shield, strongly convex, but less elevated than the cheek-lobes, bounded laterally and anteriorly by deep grooves, the anterior being not so deep as the posterior. The sides of the glabella are impressed and divided into lobes by three pairs of deep lateral glabellar furrows. Those of the posterior pair are the longer and more deeply impressed. These furrows begin abruptly at a point somewhat in advance of the middle of the longer diameter of the glabella, and directed backwards at an angle of about 45° to the antero-posterior diameter of the shield, disappear abruptly without gaining the medial line, usually extending a little more than the third of the distance across the glabella. Those of the median pair begin also on the bounding groove very abruptly, only a little in advance of the posterior pair, but they are usually not so oblique, and extend on each side not more than a quarter of the distance across the glabella. The distance between the outer extremity of

[3] See note on this genus under remarks on the genus Ptychoparia.

the median and anterior furrows is somewhat less than between those of the median and posterior, and these but slightly impress the sides of the glabella, and occasionally are scarcely visible. The anterior lobe is about as wide as the one which follows it.

"The occipital furrow is deeply cut in the outer third of its length and strongly directed forwards; in the middle third it is not so deep and is quite strongly arched forwards. The occipital ring is narrow, strongly convex, and vertically arched, the sides being more or less narrowed, turned downwards and forwards, being projected obliquely more or less across the posterior marginal cheek-groove towards the inner posterior angle of cheek-lobe. The ring projects backwards beyond the margin, but not beyond the posterior lateral angle of shield. The middle part is produced into a very short conical tubercle-like spine, directed slightly backwards. The cheek-lobes are strongly gibbous, and very regularly arched, the convexity being stronger anteriorly. A narrow, distinct, wavy ocular ridge begins on the cheek-lobe, just opposite the anterior part of glabella, and, thinning gradually out and arching, at first slightly forwards, curves round and is directed towards the outer angle of cheek-lobe, but it usually vanishes before reaching that point. From its anterior outer side it throws off a very numerous set of fine, bifurcating, raised lines of ridges. These lines are directed outward from the primary line at a rather acute angle, and appear to bifurcate several times. This ocular ridge is thickened at its commencement, but is not so strongly marked at that point as in *C. Baileyi*. It is also more arched forward than in the latter species. The whole outer surface of the shield is covered by innumerable, close-set, raised points or granulations, just visible to the naked eye, but very distinct under the lens, appearing in the impression of the shield as minute punctures. These appear to be more distinct on the convex portions of the shield. The raised margins, cheek-lobes, glabella, occipital ring, as well as the lobe just in advance of the glabella, bear sparsely-sown, minute, short spines, which give to the surface a distinct granular appearance. These are always wanting in the furrows and on the cheek-lobes, are more crowded on the outer halves of the cheek-lobes. They are true spines, but usually appear as granulations on the casts.

"In very young specimens, a line in diameter, the shield is semicircular, the cheek-lobes are extremely gibbous, and very much more convex than the glabella, and the preglabellar lobe is very conspicuous."

The above description gives all the characters of the adult head of this species as shown in the specimens contained in the Hartt collection. A number of small heads show embryonic features, but as Mr. Hartt did not describe these and Mr. Matthew is at work on the species and its stages of development, we will await the appearance of his paper.

Mr. Linnarsson unites *Conocoryphe coronatus*, Barr. (Syst. Sil. de Bohême., vol. i, p. 424, plate xiii, figs. 20–26), *C. exsulans*, Linnarsson (Sv. Geol. Unders. Afh., Ser. C., N:o. 35, p. 17, 1879), *C. solvensis*,

Hicks (Quar. Jour. Geol. Soc., vol. xxvii, p. 400, plate xvi, fig. 8, 1871) and *C. Matthewi*, Hartt, as a natural group chiefly characterized by the boss or elevation in front of the glabella. He speaks of *C.* (*Elyx*) *laticeps*, Ang. (Pal. Scan., t. 5, figs. 2–3, 1854), as the nearest allied from among Swedish species, and there appears to be good reason for placing it very close to, if not in the *C. coronatus* group.

Mr. Corda proposed the generic name Ctenocephalus (Prodrom. Mon. böhm Trilobiten, p. 142) for this type of the Conocephalidæ, and in many respects it is a convenient subgeneric term.

I know of no American species from the Potsdam or Georgian horizons that will fall within the group, although a species from the Georgian horizon, in Central Nevada, *Ptychoparia Linnarssoni*, Walcott (Pal. Eureka Dist., in press), has a boss in front of the glabella much the same as that in *C. coronatus*. The presence of large, free cheeks, well marked eyes, and facial sutures, places the species in the second division of the Conocephalidæ under the genus Ptychoporia, or a subgenus of the latter.

Mr. Hartt describes a second species of this group under the name *Conocephalites gemmini-spinosus*, as follows: "Resembles *C. Matthewi*, but with wider and less elevated marginal folds; cheek-lobes much more gibbous and semi-ovoid, &c., sparsely sown with minute spines, grouped two and two. Rare, at Saint John." This species does not appear on the list of numbered specimens, and I fail to find any specimens that differ from the typical forms of *C. Matthewi* sufficiently to warrant a separate specific name. Under the circumstances it appears best to place the name as a synonym of *C. Matthewi*, on the grounds of imperfect description, no illustration, no labeled type specimen, or a form in the collection that can be recognized as the one referred to by the author. Specimen No. 91 is referred to as *C. Matthewi* var. ?. This is a well-marked variety in its surface characters, as the scattered tubercles of *C. Matthewi* are crowded together and give the glabella, cheeks, frontal lobe, and margins a granulated appearance quite unlike *C. Matthewi*. The ocular-like ridges are also lost in the crowding together of the tubercles; fig. 1 b., pl. iv.

*Formation and localities.*—Cambrian. Saint John formation, Ratcliff's Millstream, Saint John and Portland, N. B. The variety (= granulata) is labeled Cold Brook (= Portland, on authority of Mr. Matthew).

### Conocoryphe Walcotti, Matthew.

In a letter received from Mr. G. F. Matthew May 22, 1884, written since the preparation of this paper, he states that he has found a species of Conocoryphe in the Saint John formation, characterized by transverse bars on the glabella, a granulated but not tuberculated surface, and other features separating it from the other species of the genus. For this species he proposed the name *Conocoryphe Walcotti* in

a paper "On the Conocoryphidæ of the Saint John group, with remarks on Paradoxides," read before the Royal Society of Canada, May, 1884.

### Subgenus SALTERIA, n. subgen.

Dr. Henry Hicks, in his description of *Erinnys venulosa*, refers the species to Salter (Brit. Assoc. Rep., 1865), where we find the name used and the relations of the genus to Harpides pointed out, and the fact stated that it has a great number of free segments and no facial sutures and probably no eyes. The description of *Erinnys venulosa* (Quart. Jour. Geol. Soc., vol. xxviii, p. 177), is of the type species, and gives that of the genus as far as known.

*Description.*—"Ovate in form, being widest in front, and surface depressed. The largest specimens indicate a fossil at least 3½ inches long.

"Head semicircular, margined all round, but with no posterior spines wider than the body. Glabella small, occupying only about two-thirds of the length and about one-fifth of the width of the head; pyramidal in shape, slightly raised, and indented by three pairs of furrows, the hinder ones reaching backwards nearly to the neck-lobe, and marking off triangular lobes on each side.

"There are no distinctly-marked eyes or facial sutures, but a tolerably strongly-raised ridge strikes off on each side from opposite the upper glabellar lobes towards the posterior angles, reaching nearly two-thirds of the distance across. From these ridges lines strike off in each direction, especially forwards, dividing and subdividing in their course and giving a veined character to the whole surface.

"Thorax composed of 24 rings; axis narrow, convex, and tapering towards the tail; pleuræ compressed, grooved, and, including the spines, more than twice as long as the rings of the axis; spines bent backwards from the fulcrum, at which part the surface becomes suddenly raised into a sharp, transverse ridge.

"The tail is semicircular, and has a tolerably strong axis, composed of four segments. The lateral lobes are marked by four moderately well-defined ribs."

This is certainly a very remarkable form, and is, as stated by Mr. Salter, related to Harpides; still it does not appear to be congeneric with it.

The first generic use of the name Erinnys of which we have record, was by Mr. Schrank (Faun. Boica, vol. ii. pt. 1, p. 152, 1801), for a genus of Lepidoptera. Mr. Schrank spelled the name "Erynnis." Mr. Agassiz suggested in his Nomenclator Zoölogicus, 1846, that it be changed to Erinnys. The name was again used by Mr. J. Thompson (Arch. Ent., vol. i, 1857) for a genus of Coleoptera. In 1865 Mr. Salter proposed it for the genus under consideration, and in 1867 it was again proposed for a genus of Coleoptera by Mr. Oustalet (Scudder Index Univer., p. 115). As Mr. Salter's name was anticipated, it becomes

necessary to replace it, and the name Salteria is proposed in honor of the distinguished paleontologist. The generic description, as far as known, is essentially that of *Salteria venulosa*. With it we may place *S. Baileyi*, as it is an almost identical species, as far as can be determined from the head and pygidium.

### CONOCORYPHE (SALTERIA) BAILEYI, Hartt.

Plate iv, figs. 3, 3*a*; pl. v, figs. 7, 7*a*.

*Conocephalites Baileyi*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 645.

*Description.*—"Head transversely semi-elliptical, half as long as wide; anterior margin in front more or less straight; posterior margin quite straight; posterior angles of cheeks slightly rounded and unfurnished with spines; facial suture never visible; anterior margin of shield with a narrow, very elevated border, which is widest and most elevated in front, and grows narrower and lower posteriorly, becoming obsolete, or nearly so, at the posterior angle of the shield. This border is separated from the other part of the shield by a deep, rather wide furrow, which is deepest in front, but grows shallower as the anterior border loses in height going posteriorly. General form of shield convex, but much depressed; glabella more depressed than the cheek, subtriangular, depressed convex, broadly rounded in front, and separated from the cheeks and front by a deep, well-marked furrow; width at base equal to length, which last is about seven-tenths that of shield; very much narrowed in front. Lateral bounding furrows inclined to one another at such an angle as would cause them to meet if produced to the middle of the front margin of head. Occipital furrow deep and well marked, slightly arched forward in middle, and curving downward and forward, growing narrower at the extremities, and less deeply cut than the bounding furrow of the glabella. No lateral glabellar furrows, or very slightly marked, ever seen on casts. Occipital ring more elevated and rather wider in the center; bent forward at the sides; narrow, with a very low, spine-like tubercle in the center. Posterior furrow moderately deep and wide. Sides of shield bent slightly downward. Posterior angles flattened. Cheeks subtriangular, bounded by the straight dorsal furrow, the straight groove which separates them from the glabella and the curved marginal furrow. They are more convex or gibbous than the glabella, sloping gently toward the marginal furrow, but steeply to the other bounding grooves. In the cast they are marked on the edge of the bounding groove of the glabella at the points where the straight sides of the latter begin to curve around the front by two small, low, but well-marked ocular prominences, from each of which extends a slight ocular ridge, with a more or less outward curve toward the posterior angle of the shield, but usually loosing itself at about half the distance in a system of delicate ramifications, which may often be traced to the posterior angles of the cheek lobes. Like ramifications are thrown

off for the whole length of the ridge from its anterior side, and these occupy the surface of the cheek lobes in front of the line. The surface of the cast sometimes appears granular, but the mould is always smooth, and the outer surface of the shield was unfurnished with tubercular or granular ornamentation. The posterior border on each side of glabella is very elevated in the middle, and loses height thence each way. Cephalic shield sometimes an inch and a half in width."

On one specimen referred to this species the left postero-lateral angle of the head shows a short, slender, rounded spine, a feature not mentioned in the original description, and a short facial suture cuts off a slender strip of the postero-lateral side of the cheek, carrying the spine with it.

The resemblance between the head of this species and that of *C.* (*Salteria*) *venulosa* is very striking, the greatest difference appearing in the presence of a suture line and postero-lateral spine. I suspect, however, that, as in the case with *C.* (*S.*) *Baileyi*, the free cheek and spine are broken away in *C.* (*S.*) *venulosa*, and have not been observed, owing to that. One specimen of *C.* (*S.*) *Baileyi* preserves twelve segments of the thorax and the pygidium. The latter is of the type of that of *C.* (*S.*) *venulosa*, but the thoracic segments vary considerably at the genal angle of the pleural lobes and in the rounded instead of falcate terminations of the pleuræ. The true number of segments in the thorax is unknown.

*Formation and locality.*—Cambrian. Saint John formation. Ratcliff's Millstream, N. B.

### CONOCORYPHE ELEGANS, Hartt.

Plate iv, figs. 2, 2*a*, *b*.

*Conocephalites elegans*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 650.

*Description.*—"Head or cephalic shield semi-circular or semi-elliptical, more than twice as broad as long, nearly straight behind; anterior border with a very strong fold, separated from the rest of the head by a deep groove. This fold is widest and most elevated just in front of the glabella, where it is sometimes the tenth of an inch in width. At this point the groove bends abruptly and angularly, and arches forward on each side so as to encroach on the marginal fold and cause it to disappear at about half the distance between the middle point in front and the posterior angles of shield. The posterior marginal folds are very thin, most elevated in the middle, and sloping each way towards the occipital ring and posterior angles of shield. The axis of the outward half is more and more inclined backward from the perpendicular towards the posterior angles, which are rounded, more or less flattened, and without backward projecting spines. The grooves separating the posterior fold from the cheeks are very deep, and are slightly directed forward. Length of glabella about sixth-tenths of antero-posterior diameter of

shield, a little wider at base than long, and less than half as wide anteriorly; triangular, with anterior part rather broadly rounded, highly inflated, and bounded by deep grooves, which in front join in with the anterior marginal groove. There are three pairs of glabellar furrows. Those of the posterior pair impress deeply the sides of the glabella, are strongly curved backwards, and scarcely reach a third of the distance across each side. The second and third pairs only just impress in like manner the sides of the glabella. Those of the second pair are curved backward, and extend about a quarter of the distance across the glabella. Those of the third pair are very short, and appear to be parallel with the transverse diameter, but they are not always distinct.

Occipital furrow deep, slightly arched forward in the middle, and with the ends turned in the same direction; occipital ring of moderate width; the middle is produced into a spine often more than a quarter of an inch in length. This spine is more or less strongly directed backwards. The cheek lobes are very gibbous, more so than the glabella. Their posterior border is so strongly impressed by the posterior furrow that it arches slightly over it. The surface of the convex part of the shield is ornamented by very fine, close-set granulations, distinctly visible to the naked eye, and by a set of delicate little tubercles more sparsely sown."

This distinct and finely ornamented species may be compared with *Conocoryphe bufo*, Hicks (Quart. Journ. Geol. Soc., vol. xxv, p. 52, 1869). In the form of the head, frontal margin, and glabella, the character of the granulose surface and absence of facial sutures and eyes, as far as known, they are very much alike. We know of the presence of the postero-lateral spines of the head in *C. elegans*, but not the occipital spine in *C. bufo* which is present in *C. elegans*. *Conocoryphe Dalmani*, Angelin (Pal. Scan., p. 63, pl. xxxiii, fig. 16, 1854), belongs to the same group of species and is very closely related to them. Linnarsson speaks of *C. tenuicincta*, Linn., *C. emarginata*, Linn., *C. Dalmani*, and *C. bufo* as forming a natural group (Sv. Geol. Unders. Afh., Se. C. N:o. 35, p. 20, 1879), and with these we add *C. elegans*, as it is a similar type and nearly identical with *C. bufo* and *C. Dalmani*.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B.

## Genus PTYCHOPARIA, Corda.

*Ptychoparia* Corda, 1847, Prodrom. Mon. böhm. Trilobiten, p. 141, Abh. den K. Böhm. Gesells. den Wissenschaften.

= Conocephalus Zenker, 1833 (in parte); Solenopleura, Angelin, 1851 (in parte); Crepicephalus, Owen, 1852 (in parte); Conocephalites, Barrande, 1852 (in parte).

In looking up the history of the generic names Conocephalus, Conocoryphe, Ptychoparia, and Conocephalites, we find that Conocephalus was first proposed by Mr. Zenker in 1833, with *C. Sulzeri* as the type, *a trilobite* without eyes and having a peculiar direction to the facial *sutures of* the head.

In 1839 Mr. Emmrich described, as a distinct species from *C. Sulzeri*, *Conocephalus striatus*, referring it to the same genus, although it has well-developed eyes and a direction of the facial sutures unlike that of *C. Sulzeri*.

Mr. Corda, in 1847, observed that *C. Sulzeri* and *C. striatus* represented two generic groups, and as the name Conocephalus had been preoccupied for a genus of insects in 1812, he proposed two generic names for the two types, Conocoryphe being given to *C. Sulzeri* and Ptychoparia to *C. striatus*. This division appears to me to be one demanded by the characters of the two types, and I fully indorse the opinion of the late Mr. F. B. Meek (Sixth Ann. Rep. U. S. Geol. Surv. Terr. 1872, p. 487), that Mr. Corda's names should be adopted and the subsequent name, Conocephalites, proposed by Mr. Barrande in 1852, treated as a synonym. Mr. Corda used the same type species in proposing the genus Conocoryphe, and there does not appear to be sufficient reason for refusing to adopt the name. Of the value of the genus Ptychoparia paleontologists may differ, but if we unite before our minds the characters of *Ptychoparia striata* and *P. Emmrichi*, the types referred to by Mr. Corda, and then bring together the group represented by *Conocoryphe Sulzeri*, *C. coronatus*, *C. exsulans*, Linnarsson, *C. solvensis*, Hicks, and *C. Matthewi*, Hartt, in the same manner, we will observe differences that, to me, appear to be of undoubted generic value. This division may be carried still further if we adopt Mr. Corda's third division of Conocephalus, Ctenocephalus, as a subgenus of Conocoryphe, and place *C. coronatus*, *C. Matthewi*, *C. exsulans*, and allied species under it From Mr. G. F. Matthew's study of *C. Matthewi* I am very much inclined to adopt Ctenocephalus in that manner.

Mr. Meek (*loc. cit.*) thinks that in adopting this view the generic name Ptychoparia will necessarily be applied to nearly all the species of the Conocephalidæ described from American rocks. With some considerable exception this is true, and especially so of the group placed under the generic name of Crepicephalus, by Messrs. Hall and Whitfield (Geol. Expl. Fortieth Par., vol. iv, p. 209, 1877). They revived the genus which was proposed by Mr. Owen (Geol. Surv. Iowa, Wis., and Minn., p. 576), making *C. Haguei* the first species.

For the purpose of placing before all the means of comparing the types of the two genera, they are figured side by side on plate v. *Ptychoparia striatus*, the type of the genus, has two more segments in the thorax than *P. Haguei*, but that is not a character of generic value of itself. Of Mr. Owen's type of the genus Crepicephalus, *C. Iowensis*, only the head is known, although the pygidium usually associated with the head is peculiar and might give rise to a subgeneric group, but not as defined by Mr. Owen or Messrs. Hall and Whitfield.

*Ptychoparia Emmrichi*, Barr. (Syst. Silur de Bohême, 1, p. 428, plate ii, Figs. 2–6), the second species arranged under the genus by Mr. Corda, differs in having the central portion of th head between the sutures in

front of the eyes narrower than in *P. striata*, a feature quite prominent in the species from the Potsdam group in Wisconsin, etc. The pygidium is also more like that of *P. Haguei*, and the pleura have less angular extremities. If the student will compare fig. 4, plate ii (Syst. Silur. de Bohême, vol. i, 1852), *P. Emmrichi*, with fig. 7 of plate xiii of the same work, I think that he will scarcely wish to place the two species in two subgeneric groups. If not, there appears to be no other way but to place Crepicephalus as a synonym of Ptychoparia for all species except *P. (Crepicephalus) Iowensis*, where it may be used as a subgenus on account of the peculiar pygidium. The genus Loganellus Devine (Geol. Canada, Pal. Foss., vol. i, p. 200), is of the same type as *Ptychoparia Emmrichi*, and is considered by Messrs. Hall and Whitfield as identical with Creciphalus = *Ptychoparia Haguei*. Solenopleura Angelin (Pal. Scan., p. 26) and Liostracus Angelin each approach this group. Liostracus represents the forms with the glabella devoid of furrows and the presence of ocular ridges on the fixed cheeks, and is a convenient subgeneric group. Solenopleura appears to be of the same character as many of the species placed under the genus Bathyurus by Mr. Billings, and I think can be used for such forms as *Bathyurus gregarius*, Billings (Pal. Foss., vol. i, p. 363), and nearly all the species referred to the genus Bathyurus from the Cambrian. The figure of the type species of Solenopleura is copied on plate vi, fig. 3.

Among the species from the Saint John formation *Ptycoparia Robbi* approaches most nearly to the typical forms of the genus Ptychoparia.

### PTYCHOPARIA ROBBI, Hartt.

Plate vi, figs. 1, 1*a*.

*Conocephalites Robbi*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 648.
*Conocephalites formosus*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 654.

*Description.*—"Head without movable cheeks, of moderate size, depressed convex, slightly arched in front, where the width is considerably less than behind; length about equal to breadth in front.

"Glabella ovate conical, sides straight, and dorsal furrows so inclined as to meet if produced in middle part of anterior margin; very convex; more elevated in the middle; posterior furrows reaching about one-third of the way across the glabella, directed strongly backwards, and reaching nearly to the base of the glabella; middle furrows less distinctly marked, short, not so oblique as first; anterior very short, appearing only as little pits or depressions on the sides of the glabella.

"Occipital ring narrow, convex, widest in the middle, narrowing towards the sides, which are turned forward, giving to it a crescent shape. Occipital furrow deep and well developed, widest in the middle, where it slightly impresses the base of the glabella; narrow and slightly bent forward at the ends. The ring bears a little, short, conical, tubercle-like spine in the middle, directed slightly backwards.

"Fixed cheeks, frontal limb one-third to one-fourth of whole length of head, with a narrow, high, convex border, inside of which is a moderately deep furrow; cheek-lobes depressed, convex, meeting in front, rising abruptly from the deep dorsal furrow, on the borders of which they reach their greatest elevation, which, however, is not equal to that of glabella, and sloping thence roundly towards the sides and front. The posterior limb bears a deep, wide, furrow, which widens somewhat near extremity. The marginal fold is very narrow and of little prominence, and widens a little in the outer half. The posterior margin bends slightly backwards at extremity of limb, which is rounded."

On comparing the type specimens of *P. Robbi* and *P. formosus*, and also a number of specimens of *P. Robbi*, I am unable to obtain good specific differences between them. The range of variation is slight and the two extremes are intimately united by specimens possessing the characters of each in a more or less fully developed condition. *P. formosus* appears to have been founded on compressed specimens of *P. Robbi*.

The representative type of *P. Robbi* occurs in the Menevian of Wales as the very closely related species *Ptychoparia* (=*Conocoryphe*) *applanata*, Salter (Quart. Jour. Geol. Soc., vol. xxv, p. 53, pl. xxv, figs. 1, 2, 4, 5). In *Ptychoparia* (=*Solenopleura*) *cristata*, Linnarsson (Afdrag ur Geol. Foreningens, i Stockholm Förhandl. 1877, N:o. 40, Band. iii, N:o. 12, p. 370), from the Paradoxides beds of Sweden, we find an allied species, and Mr. Linnarsson compares it with *P. Emmrichi*, the nearest representative of the type in Bohemia.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B.

### PTYCHOPARIA OUANGONDIANA, Hartt.

Plate v, figs. 4, 4*a–f*.

*Conocephalites ouangondianus*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 651.

*Description.*—"Head without movable cheeks; strongly convex in outline, somewhat subangular in front; much narrower in front than behind, where width is greater than the length; width in front nearly equal to length; anterior margin wide, with a strong fold, whose axis is strongly inclined forwards, so that it presents a short, steep, convex slope forward, and a long, concave slope in the inner side, being much less elevated than glabella or fixed cheeks. Glabella long, ovate-conical, nearly twice as wide posteriorly as in front; very convex, slightly subangular at the middle; sides straight, inclined to one another so as to meet in the middle of front margin if produced; rounded in front; casts sometimes showing three pairs of short, raised, transverse lines on the sides of the glabella, occupying the position of the ordinary glabellar furrows; of these the two posterior are directed obliquely backwards. In some specimens there seems to be a fourth pair in ad-

vance of the other, represented by little tubercle-like processes situated on the side of the glabella in front, just where the sides curve to the front. Glabella very much more convex than fixed cheek. Occipital ring strongly arched upward, and separated from glabella by a well-marked groove; middle of posterior margin produced backwards in a short conical spine. Fixed cheeks highest along dorsal furrow, towards which they pressed abrupt round slopes, while their general surface slopes gently and quite evenly towards front of sutures. The dorsal furrows are confluent in front with the flat margin, so that the cheek-lobes do not meet in front. They are highest along the straight dorsal furrows, but where they bend to go round the anterior extremity of glabella, the cheek-lobes narrowing and curving towards each other, gradually sink away and disappear in the front flattened space. The ocular lobes are very well developed, forming subsemicircular lappet-like lobes, curved strongly upwards, and situated about opposite the center of the head. An ocular ridge, low and rounded, but very prominent, runs from anterior margin of ocular lobes, with a curve almost parallel with front margin of shield, but slightly divergent from it to the dorsal furrow, which it gains at a point considerably back of front of glabella, and where the straight part of the dorsal furrow bends to go round the front. Posterior limb short and broadly rounded. Post-marginal furrows less deep than dorsal; wider; marginal fold narrow and moderately prominent; shield strongly arched transversely; surface smooth."

This species is more fully represented by the central portion of the head than any other in the collection. The range of variation appears to have been small originally, but the distortion by lateral and vertical compression gives it a variety of forms. Three of these are illustrated.

A small head that appears to be uncompressed looks very much like that of *P.* (*Solenopleura*) *cristata*, Linnarsson. (See description of *P. Robbi.*) Mr. Hartt speaks of this species as rather uncommon at Ratcliff's Mill stream, but on examining all the duplicate material we find upwards of forty specimens. From the character of many of the specimens it appears quite probable that some of this material was not before him when he wrote the notes on the species.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B.

### PTYCHOPARIA OUANGONDIANA, var. AURORA, Hartt.

Plate v, fig. 5.

*Conocephalites aurora*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 653.

*Description.*—"Resembles *C. ouangondianum*, but differs in wider head, more depressed; anterior margin more broadly rounded, and *border* more strongly reflexed and elevated."

To me the distinctive character between this species and *P. ouangondiana* is in the form of the glabella. Compression and distortion may give the depressed broader form and reflexed rim, but not entirely the subquadrate glabella, that appears to be a feature of original varietal importance. With a large series of specimens of this form showing its variations, the tendency will be to deprive it even of a varietal name and unite it directly with *P. Ouangondiana.*

*Formation and locality.*—With the preceding species at Ratcliff's Mill-stream, N. B.

### PTYCHOPARIA QUADRATA, Hartt.

Plate v, fig. 1.

*Conocephalites quadrata*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 654.

*Description.*—"Head minute, transversely oblong, twice as long, slightly curved in front, straight behind, very flat; a narrow elevated fold, convex in front, concave behind, and somewhat inclined backward, goes round the margin."

There appears to be but one specimen representing this species in the collection. The strongly-marked subquadrate glabella distinguishes it at once from the associated species except *P. ouangondianus*, var. *aurora*, from which it is scarcely separated by the character of the frontal rim and the stronger ocular ridges. The entire length of the head is but two millimeters.

*Formation and locality.*—Cambrian. Saint John formation. Portland, a little northward of Saint John, N. B.

### PTYCHOPARIA ORESTES, Hartt.

Plate v, fig. 3, 3a.

*Conocephalites orestes*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 649.
*Conocephalites Halli*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 654.

*Description.*—"The head-shield of this species without movable cheeks is of medium size, length about equal to breadth in front, or to two-thirds width behind; margin arched moderately in front, with a rather wide, low border fold, widest in front, narrowing toward the sides, separated from the rest of the head by a shallow groove. Glabella long, ovate, conical, or cylindrico-conical, extremely convex, wider behind than in front, where it is rounded. The sides are straight, and so inclined to one another as to meet, if produced, at a distance in advance of margin in front about equal to the distance of that line from glabella. The glabella is flattened on the sides and never regularly convex. There are three pairs of furrows, which lightly impress the sides of the glabella, and of which traces are not always distinctly preserved, and they are apt to be seen best in slightly distorted specimens. Dorsal furrow narrow, deep, and sharply cut; occipital ring widest in the middle, narrowed from behind at the sides, separated from glabella by a

distinct furrow. Bears in the middle a minute tubercular spine pointing upwards Fixed cheeks strongly convex, but much less so than the glabella, meeting in front with abrupt slopes toward dorsal and posterior marginal furrows, but with gentle rounded slopes toward sides and anterior groove. Ocular ridges, marked as lightly raised lines, originating at the dorsal furrow some distance behind the front of the glabella, and rising obliquely upwards and backwards to ocular lobes, which are small and semi-lunar, folded considerably upwards, and are situated just opposite middle of head; width between ocular lobes about equal to the width in front. Behind the eye the suture describes a long open sigmoid curve, which is continued inward somewhat so as to give the limb a rounded outline, and make the cheek here about one-third wider than at the eye. Posterior margin of cheeks with a slight fold, more prominent in the middle; outer half of this margin is arched backwards. Whole head arched slightly forward vertically."

The relations of this species are with both *P. Robbi* and *P. Ouangondiana*. From the former, the character of the frontal rim and the more elongate glabella serves to separate it, and from the latter the rounded rim-like frontal border instead of the broader flattened margin. The relations of *P. Orestes* and *P. Ouangondiana* are very close.

Specimen No. 59 is recorded in M. Hartt's list as *Conocephalites Halli*, and that name is scratched on the slate beside the specimen. The figure in the Acadian Geology (Fig. 227) was certainly not drawn from this specimen, but the description appears to have been.

*Description.*—"Well separated from all others by its very convex, narrow, and long glabella, ovate, or cylindro-conical, as well as by its strongly-rounded sub-angular outline in front, and by its peculiar anterior marginal fold."

I have studied the type specimens and also the representations of *P. Orestes* and Mr. Hartt's *C. Halli* in the collection, and it appears to be impossible to find characters that are persistent in a series of individuals to separate them as distinct species.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B. The type of Mr. Hartt's *C. Halli* is from the same locality.

### PTYCHOPARIA ORESTES, var. THERSITES, Hartt.

Plate v, fig. 2.

*Conocephalites Thersites*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 653.

*Description.*—"Differs from the last (Conocephalites Aurora) and also from *C. Ouangondianum* in the front margin being broad and flat. and bordered by a low, narrow, flattened fold or ridge, &c. Glabella in the cast has three pairs of very short raised lines on the sides."

This species appears to have been founded on a single somewhat *distorted* head, exclusive of the free cheeks. Its relations to *P. Ores-*

*tes* are very close, and I had placed it with *C. Halli* under *P. Orestes* in a preliminary study of the species. The material is so fragmentary and poorly preserved that it is difficult to satisfactorily determine the limits of many of the species.

*Formation and locality.*—Cambrian. Saint John formation, Ratcliff's Millstream, N. B.

### PTYCHOPARIA TENER, Hartt.

Plate v, figs. 6, 6*a*, *b*.

*Conocephalites tener*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 652.
*Conocephalites neglectus*, Hartt, 1868, Acadian Geology, Dawson, 2d ed., p. 654.

*Description.*—"Minute, glabella ovate-conical, truncate at base, rounded in front, where it is about half as wide as at occipital furrow, slightly contracted behind, length about equal to width at occipital furrow, strongly depressed convex, more elevated at base than at front, and higher also than fixed cheeks; aspect varies with state of preservation of specimens, arcuate, rounded, convex, or concave; the middle seems to be inclined to project back slightly over the occipital furrow, slopes abruptly to occipital furrow, which is moderately deep, wide, and narrowed, and slightly inclined forward at the ends, where it terminates abruptly; bounding groove deeper than other grooves in head; occipital ring projecting backward bodily beyond higher margin, with the axis of its fold inclined more or less backward, and produced in the middle into a short conical backward inclined spine; anterior limb regularly arched, as if the outlines of the complete head were semicircular.

"Fixed cheeks, anterior border broad, flat concave, rising more or less abruptly to a sharp, thin, marginal fold; width between anterior extremities of cheek sutures equal to or about twice width of glabella at base. Cheek-lobes but slightly convex, and much more depressed than the glabella. Ocular ridges very distinct, thin, sharp, elevated ridges, that begin about inner edge of cheek-lobes, just behind rounded front of glabella, run outward and backward at an angle of 60° to 65° to the antero-posterior diameter. They are at first straight, but soon begin to bend backward more and more abruptly, forming a fragment of a spiral, their extremities being slightly directed inwards. The width between the ocular lobes is about equal to twice the length of the glabella. The ocular ridges are inclined outwards and forwards. Another ridge of the same appearance begins a very short distance behind the origin of the former, and on the very margin of the cheek-lobes, and, diverging from the margin nearly opposite to the base of the glabella, bends off abruptly along the posterior margin of the cheek-lobe, describing a curve, whose convexity is directed backwards. This ridge terminates considerably outside of the ocular lobe, at a point distant from the glabella about equal to half the width of the latter at its base. This ridge is usually found inclined in the opposite direction to the former,

viz, inward and backward. Posterior margin of fixed cheeks moderately and regularly S curved, the inner halves curving forwards, the outer halves backwards, with a marginal fold most elevated in the middle, but much less so than the ridges of the cheek-lobe or the anterior fold. This fold becomes double at about the middle, by the appearance of a groove running along its summit, and it appears to run out before reaching the lateral suture. The width between the posterior extremities of cheek-sutures is considerably greater than between the anterior extremities or between the ocular lobes. Glabella without furrows."

This is a very striking and peculiar species, owing to the development of the sharp ocular ridges and the ridges between them and the glabella.

Associated with *P. tener* is a form described by Mr. Hartt as *C. neglectus:*

*Description.*—"Glabella regularly semi-elliptical; length, exclusive of occipital ring, about two-thirds of the width at base, moderately convex. Highest at middle of base and sloping with a regular curve toward the front. Traces of two pairs of glabellar furrows on the sides. Occipital furrow deep and concave. Occipital ring with straight parallel margins, narrow, with a short conical spine directed upward."

The type specimen, No. 341, of Mr. Hartt's list, shows the same ocular ridges as in *P. tener* and also the same ridges on the inner side of the palpebral lobes. The specimen has been compressed so as to shorten and widen the glabella, and give it the characters mentioned by Mr. Hartt. On the evidence of the material in the collection, it does not appear to represent a distinct species from *P. tener.*

*Formation and locality.*—Cambrian. Saint John formation, Portland, a little northward of Saint John, N. B.

Wishing to examine typical specimens of *Paradoxides Harlani*, the writer visited Boston, and through the kindness of Mr. Alpheus Hyatt, curator in charge of the collections of the Boston Society of Natural History, he not only obtained access to the collection from the Braintree argillites, but the loan of such specimens as were wished for study and illustration. Mr. Alexander Agassiz also gave permission to use material in the collections of the Museum of Comparative Zoölogy, and Mr. N. S. Shaler placed his private collection at the writer's disposal. It is owing to these favorable conditions that I am able to present at this time illustrations and descriptions of the fauna of the Braintree argillites.

The first notice of the presence of fossils in the patches of argillite associated with the Quincy granite in the north end of the town of Braintree, Mass., was by the late Mr. William B. Rogers, who called the attention of the members of the Boston Society of Natural History to it when exhibiting specimens of a large trilobite found at Hayward's quarry (Proc. Boston Soc. Nat. Hist., vol. vi, p. 27, 1856). Subsequently Mr. Rogers traced the history of the trilobite described by Mr. Jacob Green as *Paradoxides Harlani*, in 1834, and showed quite conclusively that it came from Hayward's quarry and was identical with the species found there. Mr. Henry D. Rogers published the best figure of the species yet given, with remarks on its discovery, &c. (Geol. Surv. Penn., vol. ii, p. 816, 1858).

Numerous collectors obtained specimens of *Paradoxides Harlani*, but it is not until 1861 that we find any notice of other species. Mr. Albert Ordway then states that he had found a fragment of a trilobite similar to that described in the Paradoxides beds of Newfoundland, in association with *Paradoxides Bennetti*, and which he referred to the genus Ellipsocephalus. He also mentions the discovery of "a distinct fucoidal impression which shows three branches, each about 4 inches long, but not sufficiently well marked to afford any evidence with regard to its nature" (Proc. Boston Soc. Nat. Hist., vol. viii, p. 6, 1862). The small trilobite is probably the same as that subsequently described by Mr. R. P. Whitfield as Arionellus = Agraulos quadrangularis (Bull. Amer. Mus. Nat. Hist., vol. i, p. 147, 1884). Mr. Ordway also published a figure of the head of *Paradoxides Harlani*, when comparing that species with *Paradoxides spinosus*, Boeck, which Mr. Barrande considered as identical with *P. Harlani* (Bull. Geol. Soc. France, vol. xvii, pp. 545–548, 1860).

In the year 1863 a restored figure of *Paradoxides Harlani*, by Mr. F.

B. Meek, was published in Dana's Manual of Geology and repeated in each subsequent edition of the Manual. This very well represents the general characters of the species.

The publication of the second described species by Mr. Whitfield gives a stronger interest to the fauna, which is now increased by the addition of another species of trilobite, *Ptychoparia Rogersi*, and a species of Pteropod, *Hyolithes Shaleri*.

In seeking for a fauna in the Cambrian system of North America to compare with that of the Braintree argillites, we are at once directed to the Paradoxides beds of Newfoundland by the almost perfect identity of the leading type of each locality, *Paradoxides Harlani* and *P. Bennetti*. I think it has yet to be decided that the two are distinct species. *Hyolithes excellens*, Billings (Pal. Foss., vol. ii, pt. 1, p. 70, 1874), is very closely related to *H. Shaleri*, more so than to any other American species, and *Agraulos socialis*, Billings (*loc. cit.*, p. 71), is of the same type as *A. quadrangularis*, Whitfield, as shown by figure 1 of plate vii. *Ptychoparia Rogersi* does not appear to be represented in the Newfoundland Paradoxides beds, unless it be by *Ptychoparia* (*Solenopleura*) *communis*, Billings (*loc. cit.*, p. 72).

Mr. Barrande has shown the strong resemblance between *Paradoxides spinosus*, of the Bohemian Basin, and *P. Harlani*; and the Paradoxides beds of Sweden, Bohemia, Wales, Newfoundland, and Braintree have frequently been correlated in a general manner by authors.

## Genus HYOLITHES, Eichwald.

### HYOLITHES SHALERI, n. sp.

Plate vii, figs. 4 4*a–c*.

Form an elongate triangular pyramid, slightly arching towards the dorsal side and expanding regularly from the apex towards the aperture. Transverse section midway of the length, semielliptical, with a width twice as great as the height; the lateral angles acute. Ventral face gently convex transversely, curving slightly longitudinally. Dorsal face strongly convex, and showing a slight tendency to become angular at the center, a little concave longitudinally. From the direction of the surface lines the aperture appears to have been oblique. Operculum unknown. Surface marked by lines of growth that on the dorsal side are nearly transverse, and on the ventral side arched forward; traces of fine longitudinal lines are shown in the matrix of the ventral side.

*Dimensions.*—Length, about 90$^{mm}$; breadth of aperture, 23$^{mm}$; height of aperture, about 14$^{mm}$. The apex is broken away, and the aperture a little crushed by compression.

The most nearly related American species is *Hyolithes excellens*, Billings (Pal. Foss., vol. ii, pt. 1, p. 70, fig. 39, 1874), from Smith's Sound,

Trinity Bay, New Foundland. Mr. Billings's description and figures lead me to think that the two species are closely allied, but still distinct, species.

The specific name is given in honor of the discoverer of the specimen illustrated, Mr. N. S. Shaler, Paleontologist of Harvard University.

*Formation and locality.*—Lower Cambrian. Braintree argillites, Hayward's Quarry, South Braintree, Mass.

## Genus PARADOXIDES, Brongniart.

### PARADOXIDES HARLANI, Green.

Plate vii, fig. 3; plate viii, figs. 1, 1*a–e*; plate ix, fig. 1.

*Paradoxides Harlani*, Green, 1834, Amer. Journ. Sci., vol. xxv, p. 336.

Rogers, Wm. B., 1856. Proc. Boston Soc. Nat. Hist., vol. vi, pp. 27–29, pp. 40–44; *ibid.*, Stodder, p. 369. Rogers, Wm. B., also in Amer. Jour. Sci., 2d ser., vol. xxii, p. 296. Rogers, H. D., 1858. Geol. Penn., vol. ii, p. 816. fig. 590.

Ordway, 1861. Proc. Boston Soc. Nat. Hist., vol. viii, pp. 1–5; *ibid.*, Jackson, p. 58.

Dana, 1863. Manual of Geology, p. 189, fig. 245. This figure appears in each subsequent edition of the Manual.

Compare *Paradoxides spinosus*, Boeck.

Mr. Green's original description is as follows:

*Description.*—"The contour of the buckler in this species cannot be satisfactorily determined from our present specimen; the anterior and posterior parts of it are well defined, but the cheeks on each side are either mutilated or obscured. The *front* is very much elevated above the surface of the cheeks. It rises a little before the anterior edge of the buckler, is rounded in front, and gradually tapers towards the middle lobe of the abdomen, with which it forms a regular continuation. On its posterior surface there are three transverse furrows; the upper one crosses it a little obliquely, and there is on each side above a considerable protuberance. The *cheeks* were, no doubt, in the form of spherical triangles, but whether the outer angles terminated in acute prolongations cannot, from our specimen, be determined. The *organs* of *vision* appear to be entirely wanting. There are two shallow depressions on each side of the cheeks, commencing near the protuberances on the front, and running towards the lateral edges of the buckler. The posterior border of the buckler, where it joins the lobes of the abdomen, is marked by a transverse groove, nearly continuous with the lower transverse furrow on the front; this groove at its commencement appears to bifurcate outwards. The *abdomen* and *tail* cannot be distinguished from each other. There are seventeen distinct articulations in both. The middle lobe is very convex, and is separated from the lateral ones by a deep channel; it gradually tapers to an obtuse tip. In our specimen there is a small part of the tail of another trilobite deposited in this place, which at first sight appears to be a dislocated fragment

of our animal. The *lateral lobes* are flattened; the costal arches are very distinct near their insertion, and for about half their length, but towards their free extremities they are a good deal obliterated. There appears to have been a delicate *membranaceous prolongation* for a considerable distance beyond the solid portion of each rib. This organization is very apparent on the costal arches of the tail. There is a deep groove running obliquely over the upper surface of each rib. *Length* of the fossil about 9 inches; *breadth*, about 4 inches."

Mr. Green did not know the true locality of the specimen sent to him by Mr. Harlan, and it was not until twenty-two years after that Mr. W. B. Rogers announced the discovery of specimens of the same species at South Braintree, near Boston, Mass., identifying the locality of the specimen used by Mr. Green in his original description. The description is unaccompanied by figures, but fortunately Mr. Green made numerous casts of the type, one of which is now before me. It is the narrow form of the species, measuring 22$^{cm}$ in length by about 14$^{cm}$ in width across the back of the head, and 12$^{cm}$ across the widest portion of the thorax. The palpebral lobes and movable cheeks are broken away, also the posterior segment of the thorax and the pygidium is displaced. Mr. Green describes the species as having 17 thoracic segments; but in a very fine specimen now in the collection of the Boston Society of Natural History, 18 segments are shown between the head and pygidium; and Mr. Henry D. Rogers gives a very perfect figure with 18 thoracic segments.

Mr. Ordway, in making a comparison between that species and the Bohemian *P. spinosus* (Proc. Boston Soc. Nat. Hist., vol. viii, p. 3), gives an outline figure of the head of *P. Harlani*, which is evidently a restored figure made up from fragments.

At the request of Mr. J. D. Dana, Mr. F. B. Meek drew a figure of *P. Harlani* for the Manual of Geology, from more or less fragmentary specimens in Mr. Dana's collection. This is one of the best, but not the best (see Rogers's figure), representations of the species yet published; but in the presence of 19 segments in the thorax, and the short extension of the posterior pleuræ and other details, it varies from specimens before us. There is considerable variation in the species in the relative length and breadth of individuals. In a form similar to the type, the length is 21$^{cm}$, and the greatest breadth of the thorax 10$^{cm}$. In two broad specimens the length is 25$^{cm}$ and 35$^{cm}$; the breadth of the thorax 16$^{cm}$ and 20$^{cm}$., respectively. This variation is also shown in the pygidium, as may be seen by comparing figs. 16, *c*, *d* of plate viii. In the head the greatest variation is seen in the contour of the frontal margin and the gradual development of the frontal limb and rim. On the small specimens the frontal limb is very short and more or less rounded. With the increase in size, the space between the glabella and the marginal rim increases in width, and the latter broadens and flattens out. Our information respecting the postero-lateral spines of the head is limited. On the *narrow* form, fig. 1, plate ix, they extend back to a point opposite the

fourteenth thoracic segment; and the movable cheek, fig. 3, plate vii, shows a long, well-developed spine. There is a limited range of variation in the extension of the pleuræ of the thoracic segments, but the material for study is too limited to say what value may be placed upon it. In reviewing all the variations, I do not think that more than one species is indicated. A narrow and broad variety might be designated if thought desirable.

Of American species of the genus Paradoxides, *P. Bennetti*, Salter (Quart. Journ. Geol. Soc., vol. xv, p. 552, fig. 1, 1859), from Newfoundland, is the most nearly related. The figure accompanying Mr. Salter's description appears to have been taken from a distorted specimen, as the two specimens now before me, although imperfect, show a form very similar to that of *P. Harlani*.

Mr. Ordway has described the differences between *P. Harlani*, Green, and *P. spinosus*, Boeck (Proc. Boston Soc. Nat. Hist., vol. viii, pp. 1–5, 1861), and from my own observations and comparisons I cannot but agree with Mr. Ordway that the two species are represented. Mr. Barrande considered *P. spinosus* and *P. Harlani* as one species (Bull. Geol. Soc. France, vol. xvii, pp. 545–547, 1860). Mr. Barrande had the cast of the imperfect specimen described by Mr. Green to compare with specimens of *P. spinosus*, and photographs of three specimens sent to him by Mr. W. B. Rogers. The two species are, however, very closely related.

*Formation and locality.*—Lower Cambrian. Braintree argillites. Hayward's quarry, South Braintree, Mass.

## Genus PTYCHOPARIA, Corda.

### PTYCHOPARIA ROGERSI, n. sp.

Plate vii, fig. 2.

This species is known only by the central portions of the head, and two specimens showing portions of the thorax.

Glabella cylindro-conical, rounding rather abruptly in front, posterior pair of glabellar furrows very faintly shown in one specimen; dorsal furrow strongly defined; occipital furrow rounded, well marked and extending out across the fixed cheeks; occipital ring rather narrow, rising at the center and extending backwards in a short, strong spine; fixed cheeks of medium width, moderately convex, and sloping forward to unite with the frontal limb; ocular ridges shown only on one specimen; starting a little back of the anterior end of the glabella, they extend obliquely backward to the small palpebral lobe; frontal limb rather narrow; it curves downward for a short distance in front of the glabella and then up to the frontal rim. The facial sutures cut the anterior margin so as to leave a narrow frontal limb, and then extend obliquely outward and backward to the palpebral lobe; back of this they extend obliquely outward to the posterior margin of the head.

Thorax formed of well marked, strongly trilobed, narrow segments; the axial lobe about one-third of the entire width anteriorly, and tapering rather rapidly backward; pleural grooves very narrow. Number of segments in the thorax unknown.

The condition of the preservation of the surface renders its character uncertain. It is apparently roughened or granulose.

Owing to the lateral compression of the specimen illustrated, the form of the glabella is too elongate. In hopes of getting better specimens the further illustration of the species is deferred.

The specific name is given in honor of Mr. W. B. Rogers, the distinguished geologist, who took so strong an interest in the discovery of the Braintree paradoxides beds in 1856.

*Formation and locality.*—Lower Cambrian. Braintree argillites. Hayward's quarry, South Braintree, Mass.

## Genus AGRAULOS, Corda.

### AGRAULOS QUADRANGULARIS, Whitfield.

Plate vii, fig. 1.

*Arionellus quadrangularis*, Whitfield, 1884. Bull. Amer. Nat. Hist., p. 147, plate xiv, fig. 8.

*Description.*—"Known only by the glabella and fixed cheeks, which are of small size, and as united are subquadrangular in form and depressed convex. Glabella quadrangular a little narrower in front than at the occipital line, squarely truncate in front and destitute of any appearance of glabellar furrows. Dorsal furrows bounding the glabella, deeply marked. Fixed cheeks about half as wide as the glabella, moderately convex in the middle. Frontal limb about as wide as the fixed cheeks, convex on the surface and strongly arched on the front border; no marginal rim exists. Palpebral lobes, one of which is visible, minute, and but slightly raised above the general surface of the fixed cheek adjacent. Occipital ring narrow. General surface smooth. This species is so entirely distinct in its quadrangular glabella that there is no possibility of confounding it with any other American species of the genus."

We have two specimens of this species showing the central portions of the head and fixed cheeks. The glabella is more elongate and less quadrangular than in the type specimen which appears to be longitudinally compressed, and also without the occipital ring and the posterolateral portions of the fixed cheeks. Restoring these parts in outline on the figure given by Mr. Whitfield, leads to the conclusion that we have but one species represented by specimens, varying considerably owing to their condition of preservation. The largest head is from the collection of Mr. N. S. Shaler, and measures 18$^{mm}$ in length. A smaller head in the collection of the Boston Society of Natural History is 9$^{mm}$ *in* length, and shows a small spine on the center of the occipital ring.

The first notice of this species is by Mr. Albert Ordway (Proc. Boston Soc. Nat. Hist., vol. viii, p. 6, 1861), where he refers it to the genus Ellipsocephalus, but does not propose a specific name. Mr. J. Marcou had a specimen in his collection for many years, but it does not appear to have been noticed until studied by Mr. Whitfield.

*Formation and locality.*—Lower Cambrian. Braintree argillites, associated with *Paradoxides Harlani* at Hayward's quarry, South Braintree, Mass.

## ON A NEW GENUS AND SPECIES OF PHYLLOPODA FROM THE MIDDLE CAMBRIAN.

### Genus PROTOCARIS, n. gen.

Carapace without evidence of a dorsal suture, rounded on the dorsal line, and bent downward on the sides; without any rostrum. Body many-jointed—31 segments extending out from beneath the carapace; the last segment broader than the preceding, and terminating in two spines. Type *Protocaris Marshi.*

In comparing Protocaris (*P. Marshi*) with Hymenocaris (*H. vermicauda*) (Salter, 1852. Rep. Brit. Assoc., pt. 2, Notices and Abstracts, p. 58; Mem. Geol. Surv. Gt. Brit., vol. iii, p. 293, plate ii, figs. 1–4; plate v., fig. 25, 1866) we find that in the simple, bent or folded eyeless shield or carapace they are closely related, but in the structure of the body they differ materially. Hymenocaris has, in one instance, 9 strong segments shown in its more elongate body, the terminal one ending in three pairs of spines; usually 6 or 7 segments are seen, 8 or 9 are less frequent (Brit. Assoc. Rep. 1883, p. 219). Protocaris has 30 narrow segments, a large terminal segment or telson with two rather strong caudal or terminal spines.

### PROTOCARIS MARSHI, n. sp.

Plate x, fig. 1.

The specimen on which the genus and species is founded is compressed between the laminæ of the slate so that the entire outline of the carapace is shown and the body is widened out. As flattened the carapace is rounded, quadrangular in outline, with a more or less distinctly defined marginal rim all around. The general surface appears to have been smooth. No evidence of eyes.

The body projecting beyond the carapace is about two-thirds as long as the carapace, narrows posteriorly, and is made up of numerous narrow segments, each about one-third of a millimeter in breadth; the last segment or telson, which is 2.5$^{mm}$ long, supports two caudal spines 7 or 8$^{mm}$ in length; 30 segments appear between the posterior edge of the carapace and the telson; the segments appear to have been smooth and without a spinose or crenulated posterior margin; the telson and caudal spines also appear to have been smooth and without ornamentation.

*Dimensions.*—Total length, 42$^{mm}$; length of carapace, 21$^{mm}$; width, 26$^{mm}$; length of body, 15$^{mm}$, exclusive of caudal spines; width of body, where it passes beneath the carapace, 10$^{mm}$; at telson, 4$^{mm}$.

The specific name is given in honor of Prof. O. C. Marsh.

*Formation and locality.*—Middle Cambrian. Georgian formation. Parker's farm, town of Georgia, Vt.

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## PLATE I.

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Fig. 1. ORTHIS BILLINGSI ..... 17

1. Cast of a ventral ? valve having fasciculate or bifurcate costæ, enlarged to two diameters.

1*a*. A small ventral valve doubtfully referred to this species, enlarged to three diameters.

1*b*. Cast of a ventral valve with sharp radiating costæ, enlarged to two diameters.

1*c*. Exterior surface of a dorsal ? valve marked by simple costæ crossed by fine concentric undulating striæ, enlarged to three diameters.

1*d*. Interior cast of ventral ? valve, enlarged to two diameters.

Fig. 2. EOCYSTITES PRIMÆVUS ..... 14

2. Enlargement to four diameters of a single plate.

Fig. 3. HARTIA MATTHEWI ..... 19

3. Interior of shell, enlarged to twelve diameters.

Fig. 4. ACROTHELE MATTHEWI ..... 15

4. Dorsal valve, enlarged to two diameters.

4*a*. Supposed ventral valve, enlarged to four diameters.

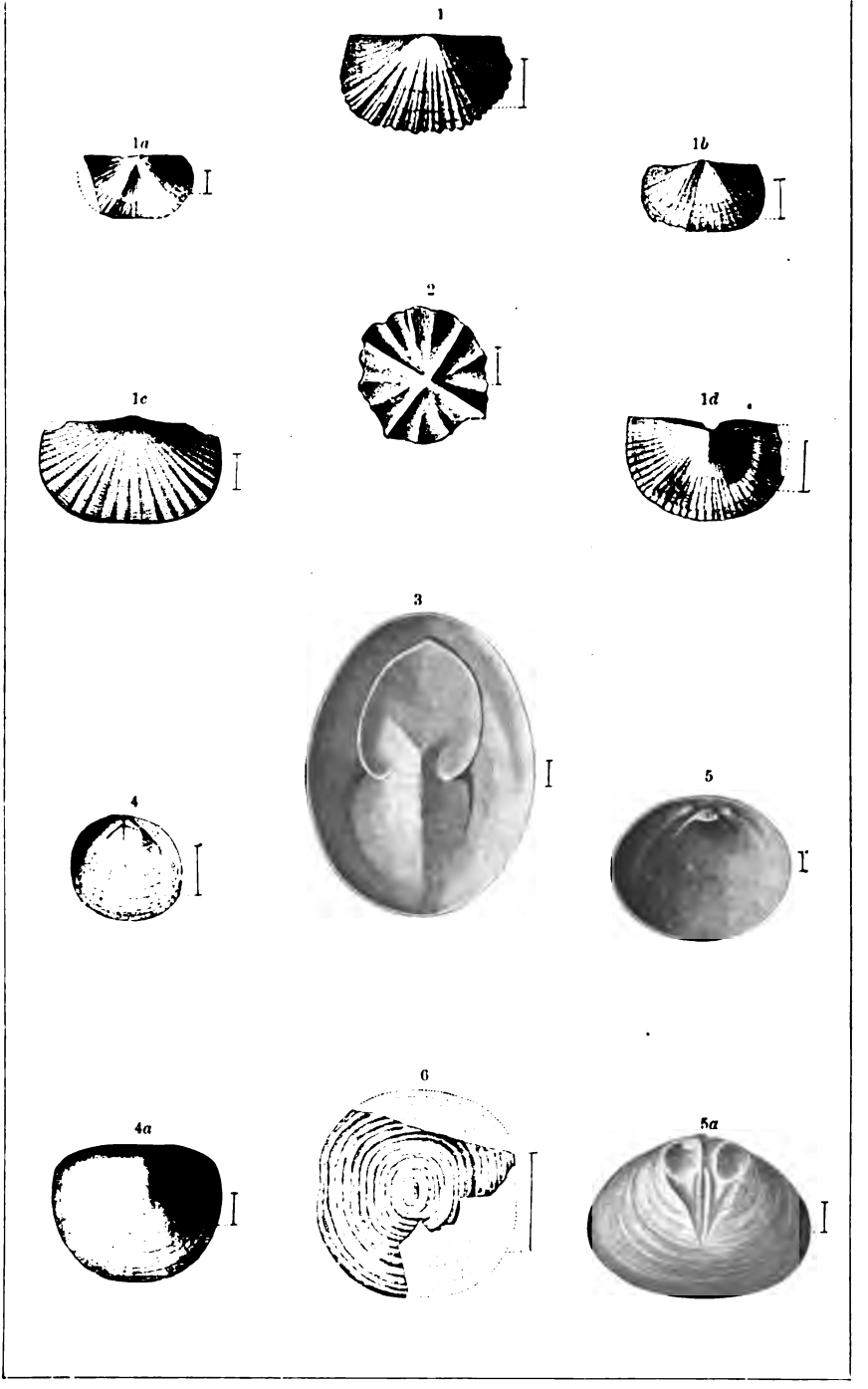
Fig. 5. OBOLELLA TRANSVERSA ..... 16

5. Interior of ventral valve, enlarged to eight diameters.

5*a*. Cast of the interior of the dorsal valve, enlarged to six diameters.

Fig. 6. PALÆACMEA ? ACADICA ..... 19

6. View of the type specimen of *Discina Acadica*, Hartt, enlarged to two diameters.




BRACHIOPODA AND GASTEROPODA.

## PLATE II.

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1, 1*a*, *b*. Head shields showing variations, enlarged to four diameters.
1*c*. Pygidium, enlarged to three diameters.

Fig. 2. AGNOSTUS ACADICUS ..... 22
2*a*. Head shield, enlarged to three diameters.
2, 2*b*, *c*. Pygidiæ, enlarged to three diameters.

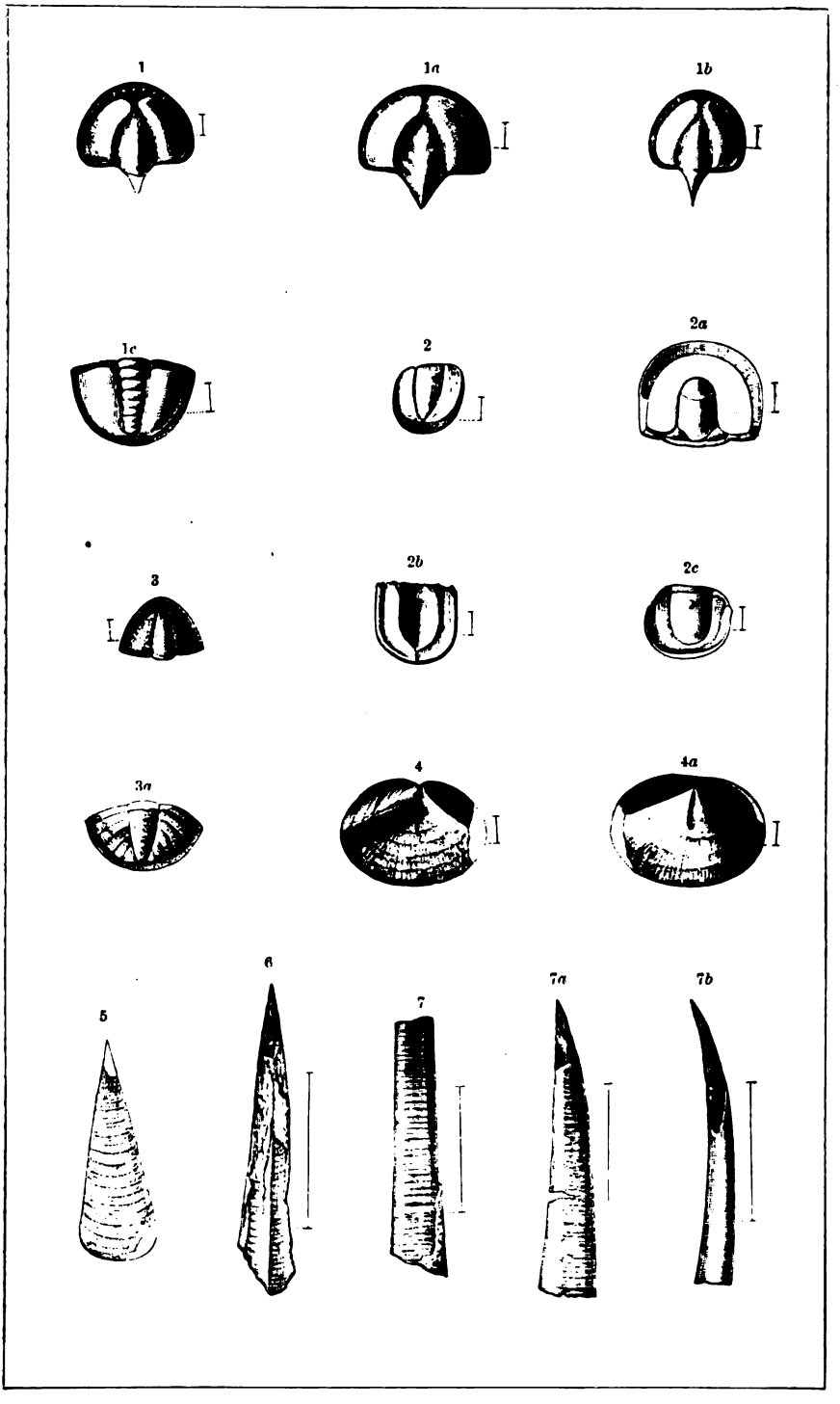
Fig 3. MICRODISCUS DAWSONI ..... 23
3. Head shield, enlarged to three diameters.
3*a*. Pygidium, enlarged to three diameters.

Fig. 4. HYOLITHES .....
4. Interior cast of operculum, enlarged to four diameters.
4*a*. Exterior of operculum, enlarged to four diameters.

Fig. 5. HYOLITHES ACADICA ..... 20
5. Ventral face, natural size.

Fig. 6. HYOLITHES MICMAC ..... 21
6. Enlargement to two diameters of the type specimen.

Fig. 7. HYOLITHES DANIANUS ..... 20
7. Dorsal view of a portion of the shell, enlarged to two diameters.
7*a*. Ventral side, enlarged to two diameters.
7*b*. Side view to show the curvature of the shell, enlarged to two diameters.




PŒCILOPODA AND PTEROPODA.

## PLATE III.

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Fig. 1. PARADOXIDES ETEMINICUS ..... 27

1. Variety *suricoides* (after Matthew).

1*a*. A small pygidium (after Matthew).

1*b*. Medium sized head, flattened (after Matthew).

1*c*. Variety *breviatus* (after Matthew).

1*d*. Variety *pontificalis* (after Matthew).

1*e*. Head of a young individual in the Hartt collection shortened by compression, enlarged to four diameters.

1*f*. Head of a young individual showing wide frontal rim, enlarged to two diameters (after Matthew).

1*g*. Head showing narrower frontal rim than fig. 1*f*, enlarged to two diameters (after Matthew).

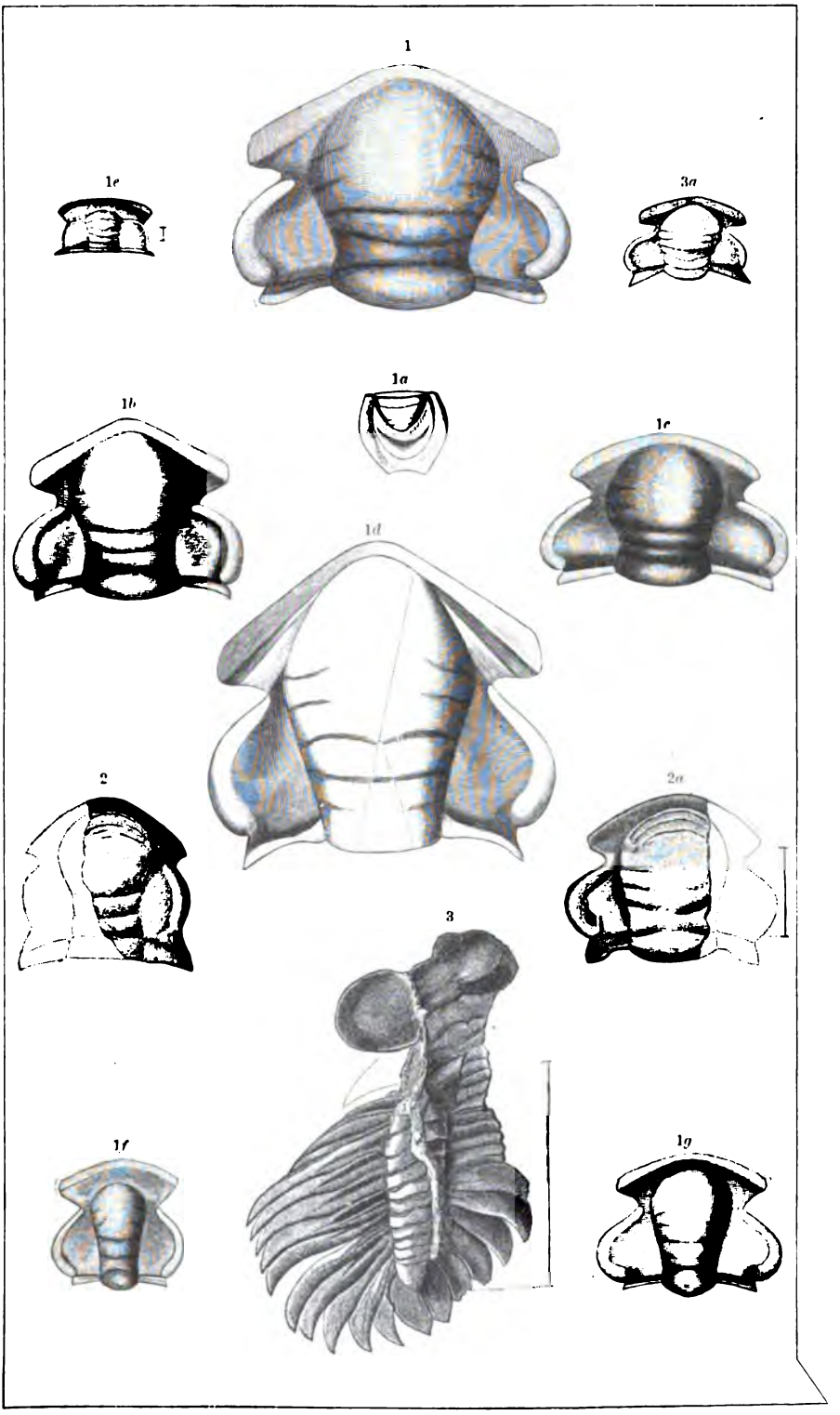
Fig. 2. PARADOXIDES LAMMELLATUS ..... 25

2, 2*a*. The two type specimens of the species. 2*a* is enlarged to two diameters.

Fig. 3. PARADOXIDES ACADICUS ..... 25

3. A distorted specimen showing the pygidium and portions of the thorax and head, enlarged to two diameters.

3*a*. Head; natural size.




PŒCILOPODA.

## PLATE IV.

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1. Head compressed longitudinally.

1*a*. Head compressed a little laterally, but nearly in its normal form.

1*b*. Finely granulose variety, enlarged to two diameters.

Fig. 2. CONOCORYPHE ELEGANS ..... 33

2, 2*b*. Heads, natural size.

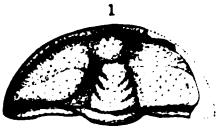
2*a*. Side of head, with genal spine attached, enlarged to two diameters. This may belong to *C. Matthewi*.

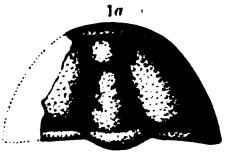
Fig. 3. CONOCORYPHE (SALTERIA) BAILEYI ..... 32

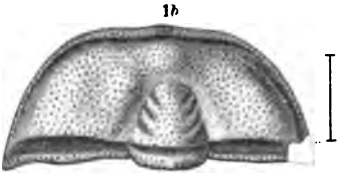
3. Large head, enlarged to two diameters.

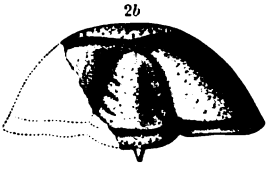
3*a*. Side of head, with genal spine attached.

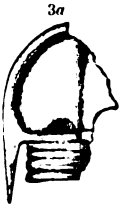
See plate v, figs 7, 7*a*.

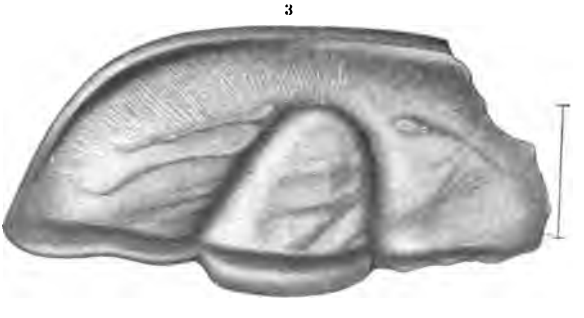




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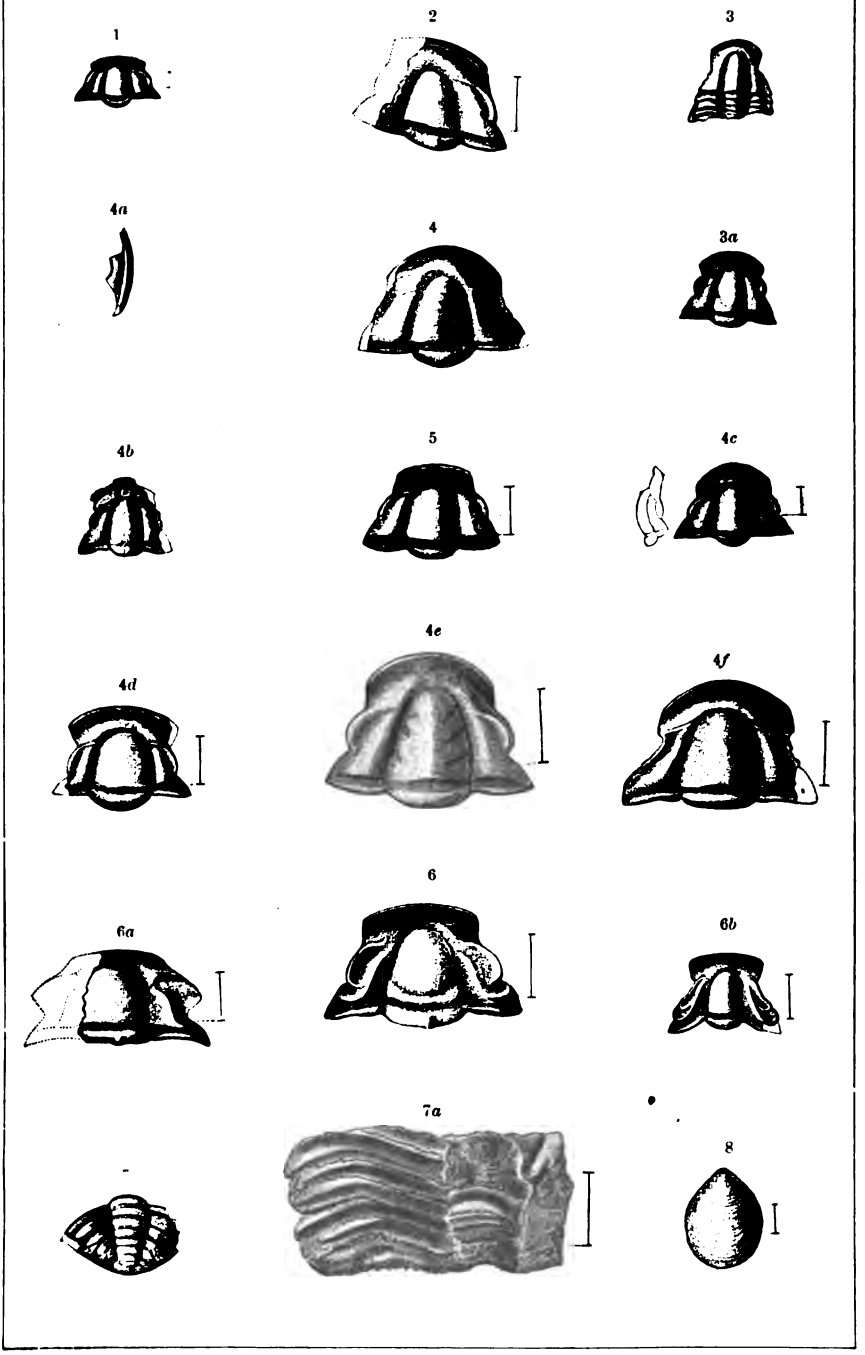


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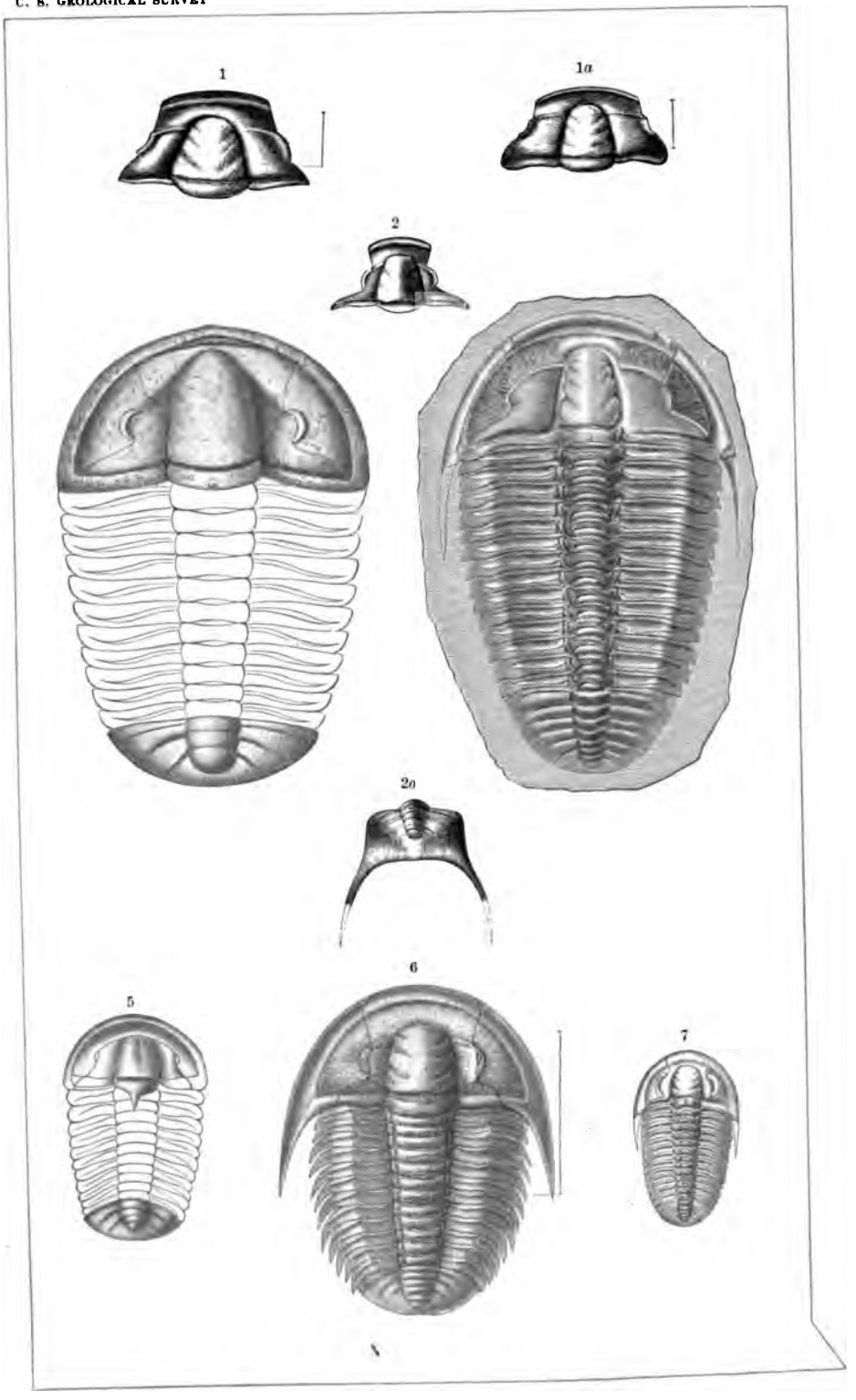


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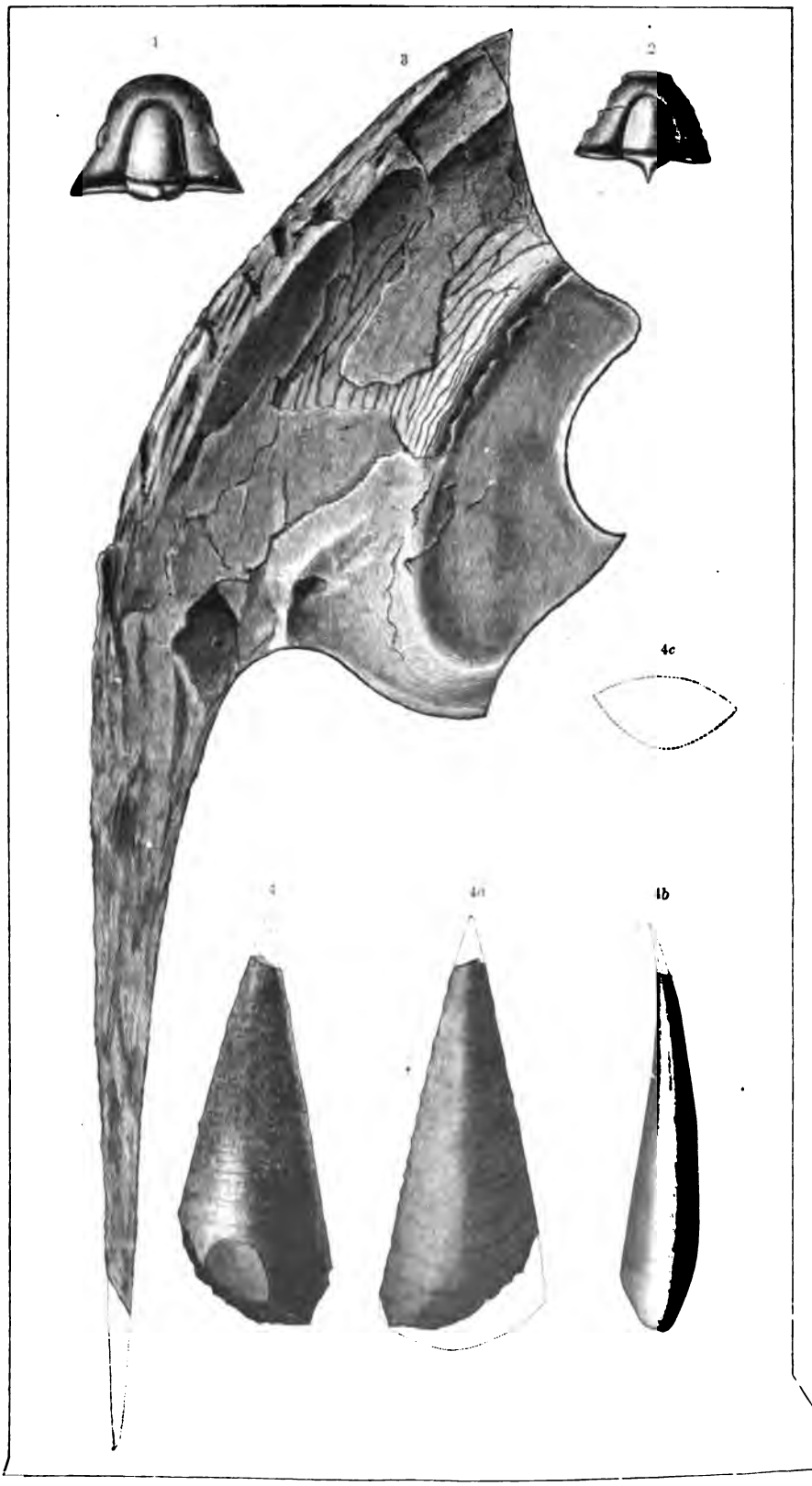
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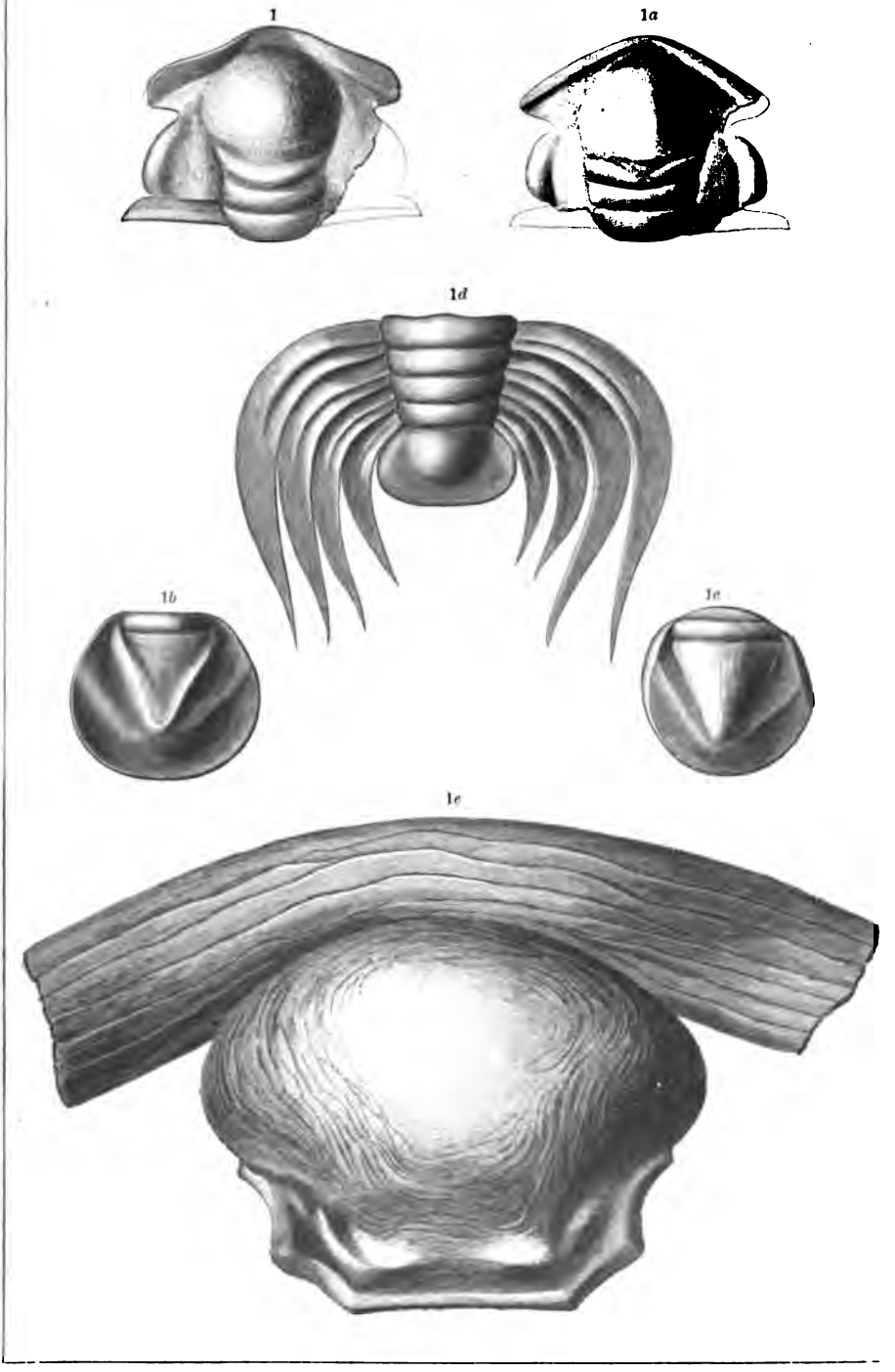


PŒCILOPODA.

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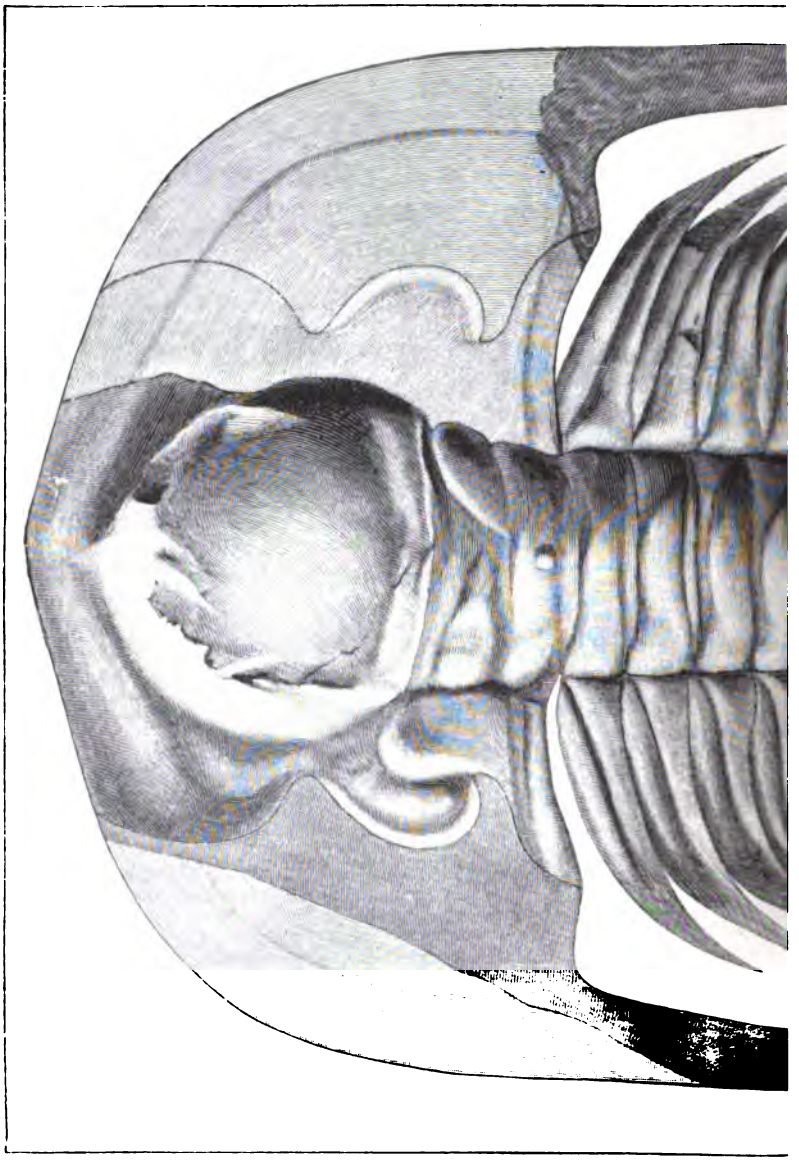

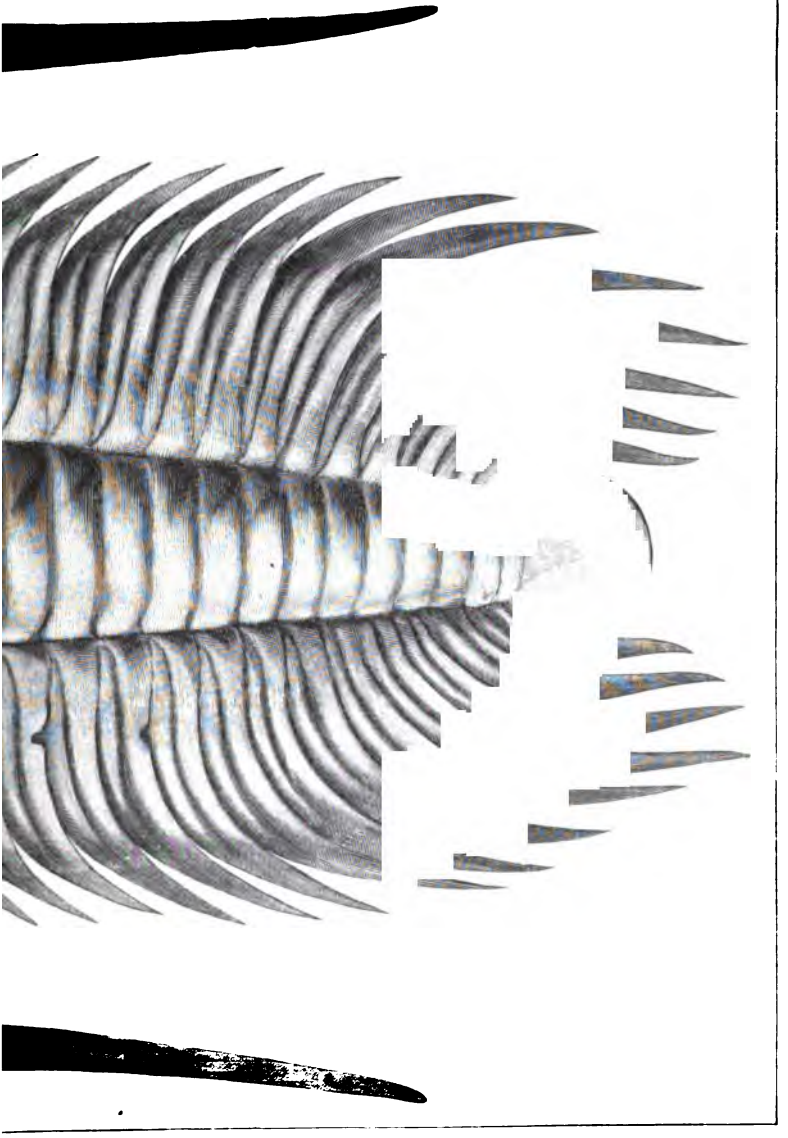

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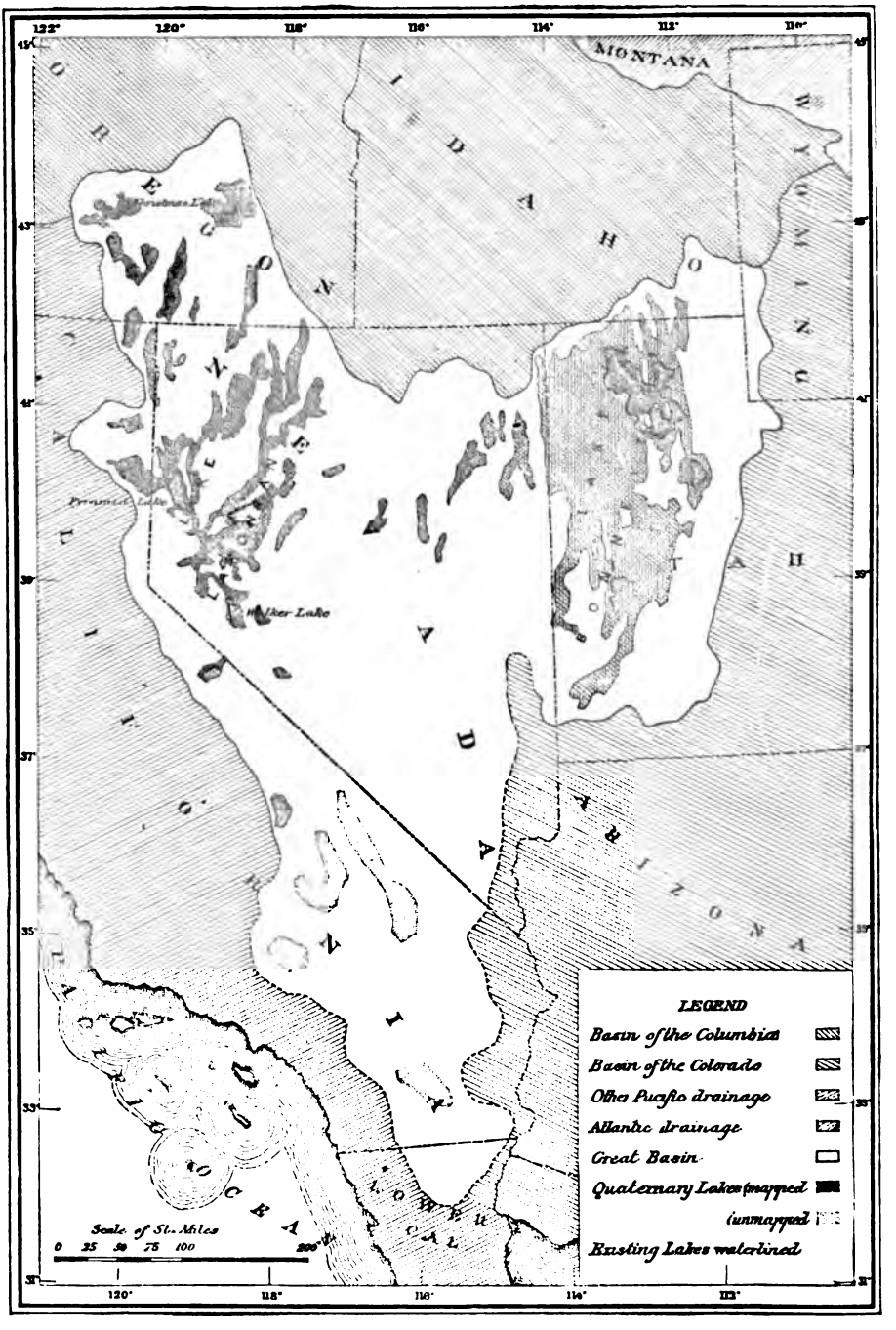


SKETCH MAP OF THE GREAT BASIN

UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL DIRECTOR

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ON THE

# QUATERNARY AND RECENT MOLLUSCA

OF THE

# GREAT BASIN

WITH DESCRIPTIONS OF NEW FORMS

BY

R. ELLSWORTH CALL

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INTRODUCED BY A

SKETCH OF THE QUATERNARY LAKES OF THE GREAT BASIN

BY

G. K. GILBERT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

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# INTRODUCTORY SKETCH OF THE QUATERNARY LAKES OF THE GREAT BASIN.

By G. K. Gilbert.

The biologic investigation reported in this bulletin grew out of an inquiry into the physical history of the Great Basin during the Quaternary. It will be introduced by a brief account of that inquiry, with especial reference to a climatic problem which it was hoped the biologic investigation would aid in solving.

During at least a portion of the Quaternary the desert valleys of the Great Basin contained a system of lakes, in comparison with which the existing lakes of the same region are insignificant. These were incidentally studied by the geologists of the surveys directed by Mr. Clarence King, Capt. George M. Wheeler, and Maj. J. W. Powell, and the outlines of the largest lakes were approximately determined. The present Geological Survey has made them the subject of an independent investigation, to the prosecution of which a corps of geologists was assigned.

The following facts have been ascertained: In the northern portion of the Great Basin there were two large water bodies; the one, Lake Bonneville, covering the Great Salt Lake and Sevier deserts, in western Utah; the other, Lake Lahontan, occupying a group of communicating valleys in western Nevada. Of smaller lakes, twenty-five have been explored, and it is probable that a still larger number remain to be examined. Previous to the epoch of Lake Bonneville its basin appears to have been arid, and the lake history was interrupted by an interval during which the water was greatly diminished, or may even have completely disappeared. There were, therefore, two floods, and corresponding to these there were two series of lacustrine deposits, separated by a zone of unconformity. The lower Bonneville beds are thicker than the upper, whence it is believed that the earlier flood was of longer duration than the later. There was a parallel series of events in the Lahontan Basin. The water rose and fell twice, and the beds deposited during the first rise form a thicker series than those deposited during the second.

This correspondence serves to confirm, and, indeed, practically to establish, the postulate early entertained that the fluctuations of these and other lakes of the region were not merely synchronous but were due to some general cause.

It has been further postulated that the general cause was climatic, and still further that it was identical with the cause of the glacial epoch, whatever that may have been. Such speculation of course implies the fact of a glacial epoch, and that fact is not universally admitted. Nevertheless, the great majority of those who have studied the vestiges of ancient glaciers believe them to have been contemporaneous in different countries, and refer them to some cause of a very general nature.

It is held, moreover, by numerous glacialists that the epoch of ice extension was bipartite, the interval being characterized by conditions comparable with those which now exist; and if this view is well sustained, then the bipartite nature of the lacustrine histories goes far toward establishing the postulate which connects them with the glacial epoch.

With regard to the general nature of the glacial climate there is not a consensus of opinion. It is indeed held by the majority of investigators that the whole earth, or at least the zones including the glaciated areas, were then colder than now, but there is a considerable body of able geologists who maintain the contrary, arguing that an extension of glaciers is rather indicative of a general amelioration of climate. It is believed that the study of the lakes of the Great Basin should throw light upon this problem, and one of the ways in which it might be supposed to contribute to the subject is through a consideration of the faunas of the ancient lakes. If these indicate a lower temperature than now obtains, the view of the majority is to that extent sustained; if they indicate a higher temperature the view of the minority is favored.

With these problems in mind, the fossil shells gathered from the Bonneville and Lahontan strata were placed in the hands of Mr. Call, and he was requested to compare them with existing forms, with a view to ascertaining whether their differences were susceptible of climatic interpretation. Finding the material too meager for the purpose, he afterward visited the region and spent several weeks in the collection of fossil and recent shells. How successful has been his quest, the reader may judge from the facts and inferences set forth in his report. Their discussion from a geologic point of view would here be out of place, but their application will soon be made by Mr. I. C. Russell and by the present writer, who have in preparation monographs on Lake Lahonton and Lake Bonneville.

Before closing, it is proper to explain two special elements of the lacustrine histories to which Mr. Call alludes in his report.

The first of these is embodied in the terms "post-Bonneville," "post-Lahontan," and "semi-fossil." Besides the shells discovered living in existing waters and the shells entombed in the Quaternary strata, there are also great numbers which lie dead and bleached on the surface of the desert at considerable distances from streams or bodies of water. These shells doubtless lived in the ancient lakes after their desiccation had commenced, and before their areas had been so greatly diminished

as we now find them. Presumably they represent climatic conditions not greatly removed from those of modern times, but they nevertheless occur at stations which are now absolutely destitute of the conditions essential to their growth. It is to shells of such occurrence that the above-quoted terms are applied.

The second special factor of the lacustrine history is embodied in the tufa deposits of the Lahontan area. These have been critically studied by Mr. Russell, who recognizes three varieties superimposed in the man-

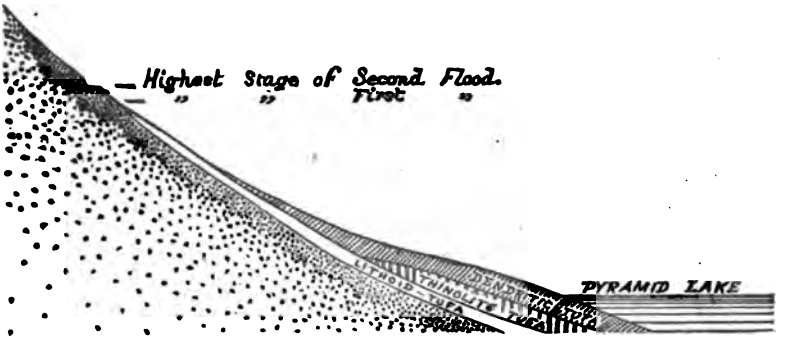


FIG. 1—Diagram showing superposition of tufas.

ner indicated by the diagram. The extreme height attained by the Lahontan waters during their first rise was 500 feet above the level of Pyramid Lake. Up to this height are found deposits of "lithoid" tufa. Over the "lithoid" tufa is deposited a distinct variety named "thinolite," but this reaches only one hundred feet above the surface of Pyramid Lake. It rests unconformably upon eroded surfaces of the lithoid tufa, and is chronologically separated from it by an epoch during which the water fell to a lower plane than that marked by Pyramid Lake. The thinolite tufa therefore belongs to the second Lahontan epoch and is synchronous with a portion of the Upper Lahontan beds. After its formation the water rose to its highest level, 530 feet above Pyramid Lake, or 30 feet higher than the first great rise. During this second high stage a third variety of tufa was deposited, the "dendritic," but it failed to attain the height of the lithoid. Its upper limit is 320 feet above Pyramid Lake. Up to the 100-foot contour it rests upon the thinolite tufa. Higher up it is found in contact with lithoid tufa. Lake Lahontan had no outlet; and it is assumed that the salinity of its water varied with expansion and contraction just as that of Great Salt Lake is now known to vary. During the lithoid and dendritic epochs it was presumably a weaker solution than during the thinolite.

The reader who cares to inform himself more fully in regard to the history of these Quaternary lakes can do so by consulting the following literature:

U. S. Geographical Surveys West of the 100th Meridian. Vol. III.

Geology. Part I. Report upon the Geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872. By G. K. Gilbert. Pp. 88–104.—Part III. Geology of portions of Utah, Nevada, Arizona, and New Mexico, explored and surveyed in 1872 and 1873. By E. E. Howell. Pp. 249–251.

U. S. Geological Exploration of the Fortieth Parallel. Vol. I. Systematic Geology. By Clarence King. Pp. 488–525.

U. S. Geological Survey. Second Annual Report. Contributions to the History of Lake Bonneville. By G. K. Gilbert. Pp. 169–200.

U. S. Geological Survey. Third Annual Report. Sketch of the Geological History of Lake Lahontan; a Quaternary lake of northwestern Nevada. By Israel C. Russell. Pp. 189–235.

U. S. Geological Survey. Fourth Annual Report. A Geological Reconnaissance in Southern Oregon. By Israel C. Russell. Pp. 435–462.

# ON THE QUATERNARY AND RECENT MOLLUSCA OF THE GREAT BASIN, WITH DESCRIPTIONS OF NEW FORMS.

By R. Ellsworth Call.

## CHAPTER I.

### SYSTEMATIC CATALOGUE OF QUATERNARY AND RECENT SHELLS OF THE GREAT BASIN.

The material herein reported upon was derived in part from collections made by the Great Basin Division of the United States Geological Survey and in part from personal collections made under the auspices of the same organization. The material comes from numerous and widely separated localities, and is fairly representative of all the beds of ancient Lakes Lahontan and Bonneville. The first-named area furnishes the greater body of material, and also exhibits the more diverse fauna.

The later beds present three identical forms in common—*Fluminicola fusca* Hald., *Helisoma trivolvis* Say, and *Limnophysa palustris* Müller—no one of which is characteristic of either area. These identical forms represent two distinct families of gasteropods, the first named belonging to the *Rissoidæ*, the others to the *Limnæidæ*. Each of these great families is represented by the characteristic species of each series of lacustrine beds, the *Limnæidæ* being alone characteristically represented in the Lahontan beds, and the *Rissoidæ* alone characteristically represented in the Bonneville beds.

The field treated in this paper is entirely new, and the methods adopted are also new. The results have been put into the form of tables of measurements, and these tables have been used as the basis of graphic representation.

The facies of the shells studied in a measure correspond with differences in size. That is to say, the weight, sculpture, and other taxonomic features were found to vary in almost or quite as marked a degree as the size.

The material upon which the included discussion is based is exhibited in the following catalogue[1]:

## LAMELLIBRANCHIATA.

### UNIONIDÆ.

#### Genus MARGARITANA.

**Margaritana margaritifera** Linn.

This species is circumpolar. It appears over a considerable area of the northeastern United States, Nova Scotia, New Brunswick, Newfoundland, and Quebec. Its western limit in this area is Central Pennsylvania. It reappears in the headwaters of the Missouri River, and thence over all of the western United States, south to Arizona and north to British Columbia. It is somewhat common in streams near Salt Lake City, Utah, and occurs rarely at Elko, Nev., in the Humboldt River. It is far smaller throughout its western range than are its eastern congeners. It has been found fossil at one locality only in the Lahontan area, in the Walker River Cañon, Nevada. Within the Bonneville area it is semi-fossil[2], or post-Bonneville, at numerous localities and notably in Sevier Desert.

#### Genus ANODONTA.

**Anodonta nuttalliana** Lea. Observations on *Unio*, Vol. II, 77 (1838). Transactions Am. Phil. Soc., Vol. VI, Pl. 20, Fig. 62 (1838).

*Anodonta wahlametensis* Lea. Trans. Am. Phil. Soc., Vol. VI, Pl. 20, Fig. 64 (1838). Obs. on *Unio*, Vol. II, 78 (1838).

*Anodonta oregonensis* Lea. Trans. Am. Phil. Soc., Vol. VI, Pl. 21, Fig. 67 (1838).

*Anodonta californiensis* Lea. Trans. Am. Phil. Soc., Vol. X, Pl. 25, Fig. 47. Obs. on *Unio*, Vol. V, 42 (1852).

*Vide* also, Stearns, "On the History and Distribution of the Fresh Water Mussels and the Identity of certain alleged species." Proc. Cal. Acad. Sci., Nov. 20, (1882), p. 4 *et seq.* In this paper a vast array of facts is brought out, together with the necessary data to render the synonymy as here given absolutely certain.

The synonymy here indicated is based upon extensive suites from various localities on the Pacific slope and in the Great Basin. In its various forms the species has a wide distribution through California, Idaho, Oregon, Washington Territory, British Columbia, Vancouver's Island, Nevada, and Utah. Specimens were dredged in Utah Lake in August 1883. In the Lahontan area it is especially abundant in the Humboldt River, and found sparingly in the Truckee River, Nevada.

[1] The bibliographic references given in connection with this catalogue are such only as are easily accessible; no attempt has been made to furnish a complete bibliography.

[2] The special use of this term is explained on page 10, *ante*.

It is found fossil in middle Lahontan beds at Mill City, Nev., and post-Lahontan beds on the desert east of Carson Lake. In the Bonneville area it has not yet been discovered in Bonneville beds, but abundant post-Bonneville fossils occur on Sevier Desert. It is somewhat common in fresh-water streams near Salt Lake City.

## CORBICULIDÆ.

### Genus SPHÆRIUM.

**Sphærium striatinum** Lam.

*Cyclas striatina* Lam. Animaux sans Vertèbres, Vol. V, p. 560, (1818).
*Sphærium striatinum* Lam. Smithsonian Misc. Coll. No. 145, p. 37, Fig. 29 (1865).

Widely distributed in the United States and Canada. Found fossil only at Rye Patch, Nev., in Upper Lahontan beds.

**Sphærium dentatum** Hald.

*Cyclas dentatum* Hald (Prime), Smithsonian Misc. Coll. No. 145, p. 40, Fig. 32 (1865).

This species was originally described from Oregon, and has a somewhat limited distribution. In the Lahontan area it occurs in Humboldt River, at Elko, and fossil in Upper Lahontan beds at Rye Patch, Nevada. It is a very abundant species in Utah Lake, where it attains a great size. Found as a post-Bonneville semi-fossil in great abundance upon the surface of Sevier Desert; occurs also in dredgings from Great Salt Lake, near the mouth of the Jordan River, whence it was doubtless drifted or floated.

### Genus PISIDIUM.

**Pisidium ultramontanum** Prime. Smithsonian Misc. Coll. No. 145, p. 75, Fig. 85 (Appendix) (1865).

This species is rare and restricted in distribution. The original specimens came from California and Oregon. Found semi-fossil near Button's Ranch, Christmas Lakes, Oregon. As a fossil it occurs (*a*) in estuary of highest Lahontan two miles southeast of Brown's, Nev.; (*b*) section on west side of Truckee River, below Reservation Bridge; and (*c*) in Upper Lahontan beds at Rye Patch, Nevada.

**Pisidium compressum** Prime. Proc. Bost. Soc. Nat. Hist., Vol. IV, 164 (1851). Smithsonian Misc. Coll. No. 145, p. 64, Fig. 67 (1865).

This species is very widely distributed, ranging from New England to California, and north into Canada. It is everywhere rare. In Lahontan beds it has been found at the base of the bone-beds on the south side of Walker River Cañon, Nevada, below the Narrows. It is there Lower Lahontan. Three specimens, living, were dredged in August, 1883, in Utah Lake.

**Pisidium abditum** Hald. Proc. Acad. Nat. Sci. Phil., Vol. I, p. 53 (1841). Smithsonian Misc. Coll. No. 145, p. 68, Fig. 72 (1865).

Twenty-seven different specific names are listed in the extensive synonymy credited to this form by Prime in his monograph. Its distribution is so wide and the local conditions to which it is subjected are so various that its extensive synonymy is not remarkable. It has been found, living, in the Bonneville area, at only one locality—City Creek, near Salt Lake City, Utah.

## GASTEROPODA.

### LIMNÆIDÆ.

#### Genus HELISOMA.

**Helisoma trivolvis** Say.

*Planorbis trivolvis* Say. Nicholson's Encyc., Pl. II, Fig. 2 (1817–18–19). Am. Conch., Pt. VI, Pl. LIV, Fig. 2 (1834).
*Helisoma trivolvis* Say. Smithsonian Misc. Coll. No. 143, pp. 115–121, Figs. 194–201 (1865).

This species is the most widely distributed form of the genus in North America, and is correspondingly variable. In the Lahontan area it is found fossil only at Rye Patch, Nev., in Upper Lahontan beds, and semi-fossil near Button's Ranch, Christmas Lake, Oregon. Living examples are very abundant at many localities, especially near Wadsworth, Nevada. In the Bonneville area it is less abundant, living. It has been found in Upper Bonneville beds, near Salt Spring Creek, and as a post-Bonneville fossil, on the surface of the Sevier Desert.

**Helisoma ammon** Gould. Proc. Bost. Soc. Nat. Hist., Vol. V, 129 (1855). Pacific Railroad Reports, Vol V, 331, Pl. XI, Figs. 12–18 (1857). Smithsonian Misc. Coll. No. 143, p. 112, Fig. 187 (1865).

Restricted in distribution to portions of California, Oregon, and Nevada. No specimens have been found in Lahontan beds, but it is abundant as a semi fossil on the surface of Humboldt Lake Basin near White Plains.

#### Genus GYRAULUS.

**Gyraulus parvus** Say.

*Planorbis parvus* Say. Nicholson's Encyc., Pl. I, Fig. 5 (1817, 1818, 1819).
*Gyraulus parvus* Say. Smithsonian Misc. Coll. No. 143, p. 139, Figs. 219–221 (1865).

Generally distributed east of the Sierra. Found in Middle Lahontan beds at Mill City, and in Upper Lahontan beds at Rye Patch, Nevada. In the Bonneville Basin it has been found only at one locality—living in a small pond at Fort Douglas, near Salt Lake City.

**Gyraulus vermicularis** Gould.

*Planorbis vermicularis* Gould. Proc. Bost. Soc. Nat. Hist., Vol. II, 212 (1847).
*Gyraulus vermicularis* Gould. Smithsonian Misc. Coll. No. 134, 128, fig. 214 (1865).

The distribution of this form is limited similarly with *Helisoma ammon*, namely, to portions of California, Nevada, and Oregon. The shells submitted are from Button's Ranch, Christmas Lakes, Oregon, and are semi-fossil.

## Genus MENETUS.

**Menetus opercularis** Gould.

*Planorbis opercularis* Gould. Proc. Bost. Soc. Nat. Hist., Vol. II, p. 212 (1847).
*Menetus opercularis* Gould. Smithsonian Misc. Coll. No. 143, 125, Figs. 208–209 (1865).

Distribution similar to the last, with the addition of Utah. In the Lahontan area found (*a*) in Upper Lahontan lake beds, above tufa, Rye Patch, Nevada, and (*b*) in an estuary of the highest Lahontan beach, two miles southeast of Brown's, Nevada, of the same age. In the Bonneville area it is not found fossil, but is living in abundance in Warm Spring Lake, near Salt Lake City.

## Genus LIMNÆA.

**Limnæa stagnalis** Linn.

This form, a true *Limnæa*, is circumpolar in distribution, and ranges to high latitudes. It formed the subject of numerous experiments, alluded to below, made by Semper with reference to its powers of endurance of cold and other unusual conditions. Rare specimens were found semi-fossil in the Humboldt sink in the Lahontan area. It abounds, as a semi-fossil, in Sevier Desert, and numerous living examples occur near Salt Lake City, and in Utah Lake at American Fork, in the Bonneville Basin.

## Genus LIMNOPHYSA.

**Limnophysa palustris** Müller.

*Helix palustris* Müller. *Teste* Rackett, Trans. Linn. Soc., Vol. XIII, 42 (1822).
*Limnophysa palustris* Müll. Smithsonian Miss. Coll. No. 143, p. 44, Figs. 60–66 (1865).

This form is circumboreal, and consequently exhibits many varieties. It is an abundant post-Lahontan fossil, and ranges downward to Upper Lahontan, in estuary of highest Lahontan beach, near Brown's, Nevada; and to Middle Lahontan in the medial stratified gravels of Mill City, Nevada. It is abundantly distributed, living and semi-fossil, throughout the Bonneville area, and is found fossil in Upper Bonneville beds, near Salt Spring Creek, Utah. It is very common and unusually large on the surface of Sevier Desert.

**Limnophysa sumassi** Baird. Proc. Zoöl. Soc. London, p. 68, 1863. Smithsonian Misc. Coll. No. 143, p. 43, Figs. 56–58 (1865).

The distribution of this form is restricted to the northwestern United States, and southwestern British America. It is doubtful whether it

should be separated specifically from *L. palustris* Müll., with which it presents common taxonomic features. It is found fossil in Upper Lahontan beds at Brown's Station, Nevada. It is rare in the Bonneville area and fossil only at Matlin Pass, in Upper Bonneville beds, above the intermediate beach.

**Limnophysa bulimoides** Lea. Proc. Am. Phil. Soc., Vol. II, 33 (1841). Smithsonian Misc. Coll. No. 143, 61, Fig. 96 (1865).

This species is very restricted in distribution, being found only in parts of California, Nevada, Oregon, and Washington Territory, and doubtfully credited to Idaho. Found fossil in Alkali Valley, in sand just below Lahontan beds, and semi-fossil at Button's Ranch, Christmas Lakes, Oregon.

**Limnophysa bonnevillensis** Call.

The description of this form is given below. No living representatives are known. It occurs in Upper Bonneville beds, being abundant at Kelton, and common in Fish Spring Valley and near Willow Springs, Utah.

**Limnophysa humilis** Say. Jour. Acad. Nat. Sci. Phila., Vol. II, 378 (1822). Smithsonian Misc. Coll. No. 143, p. 63, Figs. 99–109 (1865).

This, another protean limnæid, to which numerous specific names have been applied, ranges through all the eastern United States and west to Nevada, though not yet discovered within the Bonneville Basin. It is found fossil in Upper Lahontan beds at Rye Patch, Nevada.

## Genus PHYSA.

**Physa gyrina** Say. Jour. Acad. Nat. Sci. Phila., Vol. II, 171 (1821). Smithsonian Misc. Coll. No. 143, p. 77, Figs. 130–132 (1865).
*Physa elliptica* Lea. Trans. Am. Phil. Soc., Vol. V, 115, Pl. XIX, Fig. 83 (1837).

This variety (?) of *Physa heterostropha* Say has not been found west of this area, where it is common. As a fossil it occurs only in Upper Bonneville beds, near Salt Spring Creek, Utah. The variety, to which Mr. Lea gave the name of *elliptica*, is found abundantly and of large size in Warm Spring Lake, near Salt Lake City. The range of the species is great, extending from this area eastward to Maine.

**Physa heterostropha** Say.

*Limnæa heterostropha* Say. Nich. Encyc., Pl. I, Fig. 6 (1817–1818–1819).
*Physa heterostropha* Say. Smithsonian Misc. Coll. No. 143, Figs. 144–152 (1865).

This, one of the earliest described *Physæ* of the United States, presents the greatest geographical range, and furnishes correspondingly numerous varieties. These varieties have been identified with the typical form to the number of thirteen, and there is evidence that a careful study will sensibly increase the synonymy. The species has not been found in the lake beds of either basin, but exists in some abundance as a semi-fossil on the surface of Sevier Desert.

**Physa lordi**, Baird. Proc. Zoöl. Soc. London, p. 68 (1863). Smithsonian Misc. Coll. No. 143, p. 76, Figs. 125–127 (1865).

This form is rare as a fossil, and has yet to be discovered living in the Bonneville Basin. A few examples have been found upon the surface of the Sevier Desert. The species is widely distributed in British America and in the northern United States, from Michigan westward.

**Physa ampullacea** Gould.

*Physa bullata* Gould. Proc. Bost. Soc. Nat. Hist., Vol. V, 128 (1855). Name preoccupied and changed by author *in lit.* to *Physa ampullacea*.

*Physa ampullacea* Gould. Smithsonian Misc. Coll. No. 143, p. 79, Figs. 134, 135 (1865).

While no specimens of this form are known in the Lahontan area, specimens have been used in the included discussion from contiguous localities in the Mono Basin, California. In the Bonneville area the species is a common one, living; this area also marks its most eastern known limit of distribution.

**Physa humerosa**, Gould.

Proc. Bost. Soc. Nat. Hist., Vol. V, 128 (1855). Smithsonian Misc. Coll. No. 143, 92, Fig. 157 (1865).

Colorado Desert, north to Pyramid Lake, in which it is living. Formerly abundant, judging from the thousands of semi-fossils on the surface of the desert. Known, living, only as above.

## Genus RADIX.

**Radix ampla** var. *utahensis* Call.

A few specimens of this form were dredged in Utah Lake in August, 1883, and are described herein. The superficial features would be perhaps insufficient to establish the variety, but the dentition differs from typical *R. ampla* Mighels very materially. The specimens sustain to *R. ampla* a similar relation to that exhibited by *Pompholyx costata* Hemphill, a strongly marked variety of *P. effusa* Lea. The relation which it may genetically sustain to *Polyrhytis kingii* Meek, from the Tertiary of Cache Valley, Utah, is below indicated.

## Genus POMPHOLYX.

**Pompholyx effusa** Lea. Proc. Acad. Nat. Sci. Phila., Vol. VIII, 80 (1856). Smithsonian Misc. Coll. No. 143, 74, Fig. 119 (1865).

*Pompholyx solida*, Dall. Ann. Lyc. Nat. Hist. N. Y., Vol. IX, 333–361, Pl. II (1870).

*Pompholyx costata*, Hemphill. (Ms).

This species, with its varities *P. costata* Hemphill, from the Dalles, Oregon, and *P. solida* Dall, from White Pine, Nev., is the characteristic fossil of the Lahontan beds, and is also highly characteristic in the modern fauna of that area. It is the only fossil found ranging from Lower to Upper Lahontan strata, and occurs at many localities, often in the greatest abundance. It is one of the three forms now living in Pyramid Lake, but of a size far below that which it formerly attained. The principal variant features which it presents are below alluded to.

### Genus CARINIFEX.

**Carinifex newberryi** Lea.

*Planorbis newberryi* Lea. Proc. Phila. Acad. Nat. Sci., 41 (1858).
*Carinifex newberryi* Lea. Smithsonian Misc. Coll. No. 143, 74, Figs. 120–122 (1865). Also Stearns, in Proc. Acad. Nat. Sci. Phila., 108–110, Figs. 25–27 (1881).

In distribution this form is restricted to portions of California, Nevada, Utah, and Oregon. In the Lahontan Basin it ranges from the shores of Walker's Lake north to Button's Ranch, Christmas Lakes, Oregon, where it is found semi-fossil. Lahontan fossils have been found only at the south end of Winnemucca Lake, contiguous to Pyramid Lake. In the Bonneville area it was discovered living in Utah Lake. The specimens were rather small, and the peculiar flattening of the apical whorls made it an unusually interesting form. This is the most eastern locality yet reported. It is probably a comparatively recent addition to the fauna of the Bonneville Basin.

### Genus ANCYLUS.

**Ancylus newberryi** Lea. Proc. Phila. Acad. Nat. Sci., 166 (1858). Smithsonian Misc. Coll. No. 143, p. 145, Fig. 244 (1865).

This shell is restricted in its distribution, so far as known, to California and Nevada. It has been found fossil only in Upper Lahontan beds in the white marl at the south end of Winnemucca Lake.

**Ancylus**, sp. undt.

A single specimen of this form was dredged in Utah Lake, in August, 1883. No opportunity has been presented to complete the identification.

## RISSOIDÆ.

### Genus AMNICOLA.

**Amnicola longinqua** Gould. Proc. Bost. Soc. Nat. Hist., Vol. V, 130 (1855). Smithsonian Misc. Coll. No. 144, 87, Fig. 173 (1865).

Described by Dr. Gould from specimens collected during the progress of the Pacific Railroad surveys on the Carson Desert. Until recently no living shells of the species were known; specimens which are referred to this species collected by H. Hemphill, near Lake Point, Utah, are in the Stearns Collection, Smithsonian Institution. It is found fossil in Upper Lahontan beds at south end of Winnemucca Lake, and at Buffalo Springs. Specimens appear to be rare in the Lahontan area.

**Amnicola cincinnatiensis** Anth.

*Paludina cincinnatiensis* Anth. Bost. Jour. Nat. Hist., Vol. III, pts. 1, 2, p. 279, Pl. III, Fig. 3 (1840).
*Amnicola cincinnatiensis* Anth. List of Cincinnati shells (1843). Name changed, but no description.

See the next species.

**Amnicola porata** Say.

*Paludina porata* Say. Jour. Acad. Nat. Sci. Phila., Vol. II, 174 (1821).
*Amnicola porata* Say. Smithsonian Misc. Coll. No. 144, p. 82–83, Fig. 164 (1865).

Both of these forms are abundant fossils in Upper Bonneville beds at various localities. The most abundant shell is the form referred to *Amnicola cincinnatiensis*. Some hesitation has been experienced in adopting the specific name *porata* for the less common form. Neither species is known to be now living in the district included in the Bonneville drainage.

**Amnicola dalli** Call.

This form, described herein, is somewhat abundant living in a small stream tributary to Pyramid Lake, near the north end, at Symon's Ranch. No fossil specimens of the species have been found.

## Genus PYRGULA.

**Pyrgula nevadensis** Stearns. Proc. Phila. Acad. Nat. Sci., 173. Figure, (1863). Call & Beecher, in American Naturalist, September, 1884, Vol. XVIII, Pp. 851–855. In this paper the dentition is figured.

It is somewhat doubtful whether the generic reference of this form is correct. It appears to be devoid of the canal-like production of the aperture which is almost the sole generic character of *Pyrgula*. The only locality where living forms have been found is Pyramid Lake, Nevada, where it occurs in countless thousands. No examples are known from the Lahontan beds.

## Genus FLUMINICOLA.

**Fluminicola fusca** Hald.

*Leptoxis fusca* Hald. Monograph of *Leptoxis*, 4, Pl. III, IV, Figs. 83, 84 (1847†).

The distribution of this genus is restricted, and especially is this true of the species here listed. It has been found only in portions of California, Oregon, Nevada, Idaho, and Utah. It occurs fossil in both Upper Lahontan and Upper Bonneville beds, very abundantly in the latter at Kelton and Snowville, Utah, but sparingly in the Lahontan beds at Rye Patch, Nevada. Living forms are common in the Ogden River, and abundant in Utah Lake, Utah.

## VALVATIDÆ.

## Genus VALVATA.

**Valvata virens** Tryon. Proc. Acad. Nat. Sci. Phila., 148, Pl. I, Fig. 11 (1863). Smithsonian Misc. Coll. No. 144, p. 15, Fig. 21 (1865).

Restricted in distribution to Oregon, California, Nevada, and Utah. In the Lahontan area this shell occurs somewhat abundantly as an Upper Lahontan fossil. It is an abundant semi-fossil on the surface of Sevier Desert in the Bonneville area.

**Valvata sincera** var. **utahensis** Call.

This form is another of those found to be so distinct as to require mention as a variety. Its affinities are pointed out below. It is a very abundant shell at the north end of Utah Lake at Lehi.

## PULMONATA GEOPHILA.

The collections of fossils made in the Bonneville area have not yet disclosed any land-shells, and but few have been found in the Lahontan basin. These represent but three genera and an equal number of species, none of which are abundant. They must be regarded as an adventitious fauna in the lake beds, washed down from higher land by rains and floods. As living shells they all range beyond the limits of the area.

In this catalogue reference is made only to those that have been found fossil, since our knowledge of the land-shells of the Great Basin is much less complete than that pertaining to the fresh-water mollusca. All forms credited to either the Lahontan or the Bonneville area have, however, been listed in the accompanying synoptical tables.

### HELICIDÆ.

#### Genus VALLONIA.

**Vallonia pulchella** Müll.

*Helix pulchella* Müll. Vermes, p. 30. (Title and reference quoted.)
*Vallonia minuta* Morse. Jour. Portland Soc., Nat. Hist., Vol. I, 21, Figs. 54–56, Pl. VIII, Fig. 57.
*Vallonia pulchella*, Müll. Smithsonian Mis. Coll. No. 194 p. 157, Figs. 270–272 (1869).

This is a circumboreal species, with wide southern distribution; it also ranges to high altitudes. Fossil specimens have been found in Upper Lahontan beds at Rye Patch, Nevada.

#### Genus SUCCINEA.

**Succinea stretchiana** Bland. Annals N. Y. Lyc. Nat. Hist., Vol. VIII, 168, Fig. 16 (1865). Smithsonian Misc. Coll. No. 194, p. 263, Fig. 471 (1869).

Living specimens have been found only in Nevada. The fossil material comes from Upper Lahontan beds at Rye Patch, Nevada.

### PUPIDÆ.

#### Genus PUPILLA.

**Pupilla muscorum** Linn. *Vide* Pfeiffer, Mon. Hel. Viv. Vol. IV, p. 666. Smithsonian Misc. Coll. No. 194, p. 234, Figs. 397–401 (1869).

This is another circumboreal form, with wide southern range. Fossil only at Rye Patch, Nev., in Upper Lahontan beds.

# OSTRACODA.

Among the shells submitted for study occurred many thousands of a minute ostracoid crustacean, only the generic position of which has been made out as follows.

## CYPRINIDÆ.

### Genus CYPRIS.

**Cypris sp. indt.**

A minute ostracoid crustacean is mentioned by White[3] as very abundant west of Fairview and at the head of Soldier's Creek, Utah. While he does not positively identify it, he yet thinks it to be identical with *Cypris leidyi* E. & S. The description of that species is not accessible at this time, and it is impossible to state whether the Lahontan forms are identical with the Utah form. Specimens occur abundantly in many localities in Lahontan Lake beds, and range from the surface of the highlands adjacent to the Truckee to and into the lithoid tufa at various points.

In the original description of Lake Bonneville[4] the occurrence of "Cypris?" is mentioned. The specimens are not at hand, but so far as information goes they agree in size and general appearance with those from Lahontan beds, and their specific identity is probable.

In tables I to IV following is given a synopsis of the recent and fossil shells discovered in the area studied.

TABLE I.—*Fossil Lahontan Mollusca.*

| Family. | Genus. | Species. | Remarks. |
|---|---|---|---|
| Unionidæ.... | Margaritana.. | margaritifera, Linn .. | North to British Columbia, east to Utah. |
| | Anodonta.... | nuttalliana, Lea ..... | To eastern limit of Great Basin. |
| Corbiculidæ . | Sphærium .... | dentatum, Hald..... | Occidental. |
| | | striatinum, Lam ..... | Maine to Texas to California. |
| | Pisidium ..... | ultramontanum, Prm . | Restricted. |
| | | compressum, Prm..... | Rare. |
| Limnæidæ... | Helisoma ..... | trivolvis, Say ..... | Everywhere |
| | | ammon, Gould ..... | Rare. Var. last? |
| | Gyraulus ..... | parvus, Say..... | Common. |
| | | vermicularis, Gould .. | Oregon, California, Nevada. |
| | Menetus ..... | opercularis, Gould.... | |
| | Limnophysa .. | palustris, Müll ..... | Common, circumpolar. |
| | | bulimoides, Lea..... | Restricted. |
| | | ——?..... | Casts. Species undetermined. |
| | | sumassi, Bd..... | Var. of L. palustris? |
| | | humilis, Say ..... | Common and abundant. |
| | Pompholyx... | effusa, Lea..... | Only species. Now found living in Pyramid Lake. |
| | Carinifex ..... | newberryi, Lea..... | See context. |
| | Ancylus ..... | newberryi, Lea ..... | Rare. |
| Bissoidæ..... | Amnicola..... | longinqua, Gould ..... | Only known as a fossil in the Lahontan area. |
| | Pyrgula ..... | nevadensis, Stearns... | Genus new to North America. |
| | Fluminicola .. | fusca, Hald ..... | Only one specimen found. |
| Valvatidæ ... | Valvata ..... | virena, Tryon..... | Rare. |
| Helicidæ .... | Vallonia ..... | pulchella, Müll ..... | Circumboreal. |
| | Succinea..... | stretchiana, Bld ..... | Nevada. |
| Pupidæ ..... | Pupa ..... | muscorum, Linn ..... | Circumboreal. |
| (7) | (18) | (26) | |

[3] United States Geol. and Geog. Sur. West of 100th Meridian, Vol. IV, p. 216.

[4] United States Geol. and Geog. Sur. West of the 100th Meridian, Vol. III, p. 99.

TABLE II.—*Recent Mollusca of the Lahontan Area.*

| Family. | Genus. | Species. | Remarks. |
|---|---|---|---|
| Unionidæ | Margaritana | margaritifera, Linn | Humboldt and Truckee Rivers. |
| | Anodonta | nuttalliana, Lea | Abundant on surface of Carson Desert. |
| Corbiculidæ | Sphærium | striatinum, Lam | Humboldt River. Abundant. |
| | Pisidium | compressum, Prime | Humboldt River. Common. |
| Limnæidæ | Helisoma | corpulentus, Say | Honey Lake, Walker and Quinn Rivers. |
| | | ammon, Gould | Black Rock Desert. |
| | | trivolvis, Say | Common. Abundant at Wadsworth. |
| | | subcrenatus, Say | Honey Lake, California. |
| | Gyraulus | parvus, Say | Ponds and small streams. |
| | | vermicularis, Gould | Spring south end Pyramid Lake. |
| | Menetus | opercularis, Gld | Elko. Sloughs Humboldt River. |
| | Limnophysa | palustris, Müll | Everywhere in ponds. Abundant. |
| | | sumassi, Baird | Honey Lake. |
| | | humilis, Say | Spring, south end Pyramid Lake. |
| | | bulimoides, Lea | Black Rock Desert. Quinn River. |
| | Limnæa | stagnalis, Linn | Surface of desert. White Plains. |
| | Physa | gyrina, Say | Common. |
| | | humerosa, Gould | Pyramid Lake. Carson Desert. |
| | | ampullacea, Gould | Honey Lake. Mono Valley. |
| | | heterostropha, Say | Truckee River. Wadsworth. |
| | Pompholyx | effusa, Lea | Pyramid Lake. |
| Bissoidæ | Amnicola | dalli, Call | Brook near north end Pyramid Lake. |
| | Pyrgula | nevadensis, Stearns | Pyramid Lake. Walker's Lake (living ?). |
| Helicidæ | Patula | idahoensis, Newc | *Testa* W. G. Binney. |
| | | strigosa, Gould | Do. |
| | | hemphilli, Newc | Do. |
| | Zonites | arboreus, Müll | Do. |
| | | viridulus, Mke | Do. |
| | | nitidus, Müll | Do. |
| | Conulus | fulvus, Drap | East slope Sierra Nevada. |
| | Vallonia | pulchella, Müll | Var. *costata*. |
| | Vitrina | pfeifferi, Newc | Sierra Nevada. *Testa* Binney. |
| | Succinea | sillimani, Bland | Humboldt Lake. |
| | | stretchiana, Bland | Truckee Valley. Wadsworth. |
| | | linesta, W. G. B | *Testa* Binney. |
| | | rusticana, Gould | Do. |
| Pupidæ | Pupilla | muscorum, Linn | Truckee Valley. Driftwood. |
| | | corpulenta, Morse | *Testa* Binney. |
| | Leuchochella | arizonensis, Gabb | Do. |
| (6) | (21) | (39) | |

TABLE III.—*Fossil Bonneville Mollusca.*

[P. B. = Post-Bonneville].

| Family. | Genus. | Species. | Remarks. |
|---|---|---|---|
| Unionidæ | Anodonta | nuttalliana, Lea | Semi-fossil. Sevier Desert. P. B. |
| Corbiculidæ | Sphærium | dentatum, Hald | Do. |
| Limnæidæ | Helisoma | trivolvis, Say | Upper Bonneville. |
| | Gyraulus | parvus, Say | Semi-fossil. P. B. |
| | Limnophysa | palustris, Müll | Upper Bonneville. |
| | | sumassi, Baird | Semi-fossil. P. B. |
| | | bonnevillensis, Call | Upper Bonneville. |
| | | desidiosa, Say | Do. |
| | Limnæa | stagnalis, Linn | Post-Bonneville. |
| | Physa | heterostropha, Say | Semi-fossil. P. B. |
| | | lordi, Baird | Do. |
| Bissoidæ | Amnicola | porata, Hald | Upper Bonneville. |
| | | cincinnatiensis, Anth | Do. |
| | Fluminicola | fusca, Hald | Do. |
| Valvatidæ | Valvata | sincera, Say, *var.* utahensis, Call. | Post-Bonneville. |
| Helicidæ | Succinea | linesta, W. G. B | Do. |
| (6) | (11) | (16) | |

TABLE IV.—*Recent Mollusca of the Bonneville Basin.*

| Family. | Genus. | Species. | Remarks. |
|---|---|---|---|
| Unionidæ.... | Margaritana.. | margaritifera, Linn ..... | Common throughout the basin. |
| | Anodonta..... | nuttalliana, Lea ..... | Do. |
| Corbiculidæ . | Sphærium .... | dentatum, Hald..... | Lake Utah. |
| | | striatinum, Lam ..... | Sevier River. Streams. |
| | Pisidium ..... | abditum, Hald..... | City Creek. |
| | | compressum, Prime..... | Utah Lake. |
| Limnæidæ... | Helisoma ..... | trivolvis, Say ..... | Numerous localities. |
| | Gyraulus ..... | parvus, Say..... | Camp Douglas. |
| | Menetus..... | opercularis, Gould ..... | Warm Spring Lake. |
| | Limnophysa .. | palustris, Müll..... | Everywhere. |
| | | sumassi, Baird..... | Sevier River. |
| | | humilis, Say ..... | Salt Lake City. |
| | | desidiosa, Say..... | Lehi. |
| | | caperata, Say ..... | Warm Spring Lake. |
| | Limnæa ..... | stagnalis, Linn ..... | Utah Lake. Warm Spring Lake. |
| | Radix..... | ampla, var. utahensis, Call. | Lake Utah. |
| | Physa..... | elliptica, Lea ..... | Warm Spring Lake. Var. *P. gyrina.* |
| | | gyrina, Say ..... | Everywhere. |
| | | ampullacea, Gould ..... | Numerous localities. |
| | | heterostropha, Say..... | Utah Lake. |
| | Carinifex ..... | newberryi, Lea ..... | Do. |
| | Ancylus ..... | sp. undt..... | Do. |
| Valvatidæ ... | Valvata..... | sincera, var. utahensis, Call. | Do. |
| Bissoidæ..... | Bythinella.... | binneyi, Tryon ..... | City Creek. Spring Grouse Valley. |
| | Fluminicola .. | fusca, Hald..... | Utah Lake. Ogden River. |
| Helicidæ..... | Patula..... | striatella, Anth ..... | Wasatch Mts. |
| | | strigosa, Gould ..... | Wasatch Mts. Ogden. |
| | | idahoensis, Newc ..... | Do. |
| | Hyalina..... | arborea, Müll ..... | Salt Lake City. |
| | Conulus ..... | fulvus, Drap..... | Do. |
| | Vitrina ..... | pfeifferi, Newc ..... | City Creek Cañon. |
| | Succinea..... | lineata, Binney ..... | American Fork. |
| | | sillimani, Bland..... | Shores of Utah Lake. Lehi. |
| | Vertigo..... | ovata, Gould..... .. | City Creek Cañon. |
| (6) | (22) | 34 | |

## CHAPTER II.

### DISTRIBUTION AND ENVIRONMENT.

#### GEOGRAPHIC AND CHRONOLOGIC DISTRIBUTION.

While there are certain facts of a physical character which justify the correlation in time of these lacustral beds, there exists no palæontologic evidence of that fact. The fossil mollusca are dissimilar, not only in their generic, but also in their family relations in many instances. The characteristic fossil of Lahontan—*Pompholyx effusa* Lea—is limnæid, while *Amnicola porata* Hald. and *A. cincinnatiensis* Anth., characteristic of the Bonneville beds, belong to the *Rissoidæ*. The first family is inoperculate and pulmonate; the second operculate and pectinibranchiate. Representatives of the genus *Amnicola* are now found common to both areas, but *Pompholyx* has not extended eastward into the Bonneville Basin, so far as known. But a kind of indirect evidence of correlation in time is furnished by increased abundance of fossil shells in those beds which are known to have been contemporaneous in origin with the highest level of each lake, and by their comparative paucity in those beds related to the lower stages. It is believed that this abundance or paucity may be correlated with the successive fluctuations of the lakes, and is dependent on them directly, or on the climatal conditions which caused them. If a valid argument can be based upon arbitrary estimates of the relative abundance of shells in turn based upon absolute abundance of fossils, then that abundance or paucity sustains a significant relation to humidity and to the tufa deposits in the case of Lake Lahontan. Thus, *Pompholyx* occurs sparingly in the lithoid tufa, is not found in thinolite at any point, becomes very abundant during the period of deposition of the dendritic tufa, and is found commonly but not abundantly in Pyramid Lake at the present time. These phenomena suggest a decided relation to humidity and to the varying chemical composition of the waters, which probably changed in nearly or quite the degree that humidity itself varied. Thus the history of *Pompholyx* in its relation to Lake Lahontan is most interesting but problematic. It is latterly associated with *Physa humerosa* Gould, and *Pyrgula nevadensis* Stearns, the only other mollusca now known to be living in that northern remnant of Lahontan—Pyramid Lake. *Pyrgula* has replaced *Pompholyx* in the modern lake, and, indeed, is not known in any Lahontan deposit.

The only other locality where *Pyrgula* is known to occur is in Walker's Lake, but not now in the living state. Since careful collection has failed to reveal the form in Lahontan beds or Lahontan tufas, the hy-

pothesis is justifiable that it has been introduced into each of these lakes since they became independent bodies. The genus is a new addition to the fauna of North America, is found in the mountainous districts of Europe, central Asia, and South America, and has hitherto been known to exist only in pure fresh-water lakes and at considerable altitudes.[5]

The dentition of *Pyrgula* was unknown until its abundant collection in Pyramid Lake, when its description and illustration became possible.

The wide range of *Pompholyx* in Lahontan beds makes possible a valuable comparison of the same species from localities representing stages of the lake widely separated in point of time. Such comparisons as have been instituted show that its history alone will furnish an important addition to hexicology. Specimens taken from the lithoid tufa on Anaho Island, in Pyramid Lake, when compared with those from horizons correlated with the dendritic period present the widest range among individuals. The shells from both localities are higher than Pyramid Lake forms, are much thinner, and the coiling of the whorls is much looser. The lithoid tufa specimens present a large proportion of costate forms, the ratio being as 1 to 2, while in recent specimens the ratio is as 1 to 32. The recent specimens approximate *P. effusa*, var. *solida* Dall, while in sculpture and elevation the earlier and smooth forms of the lithoid tufa approach nearest to the typical *P. effusa* Lea.

The abundance of costate forms in the earlier beds, and their comparative paucity among recent shells, is suggestive of genetic relation to *Vorticifex binneyi* Meek, of Miocene-Tertiary age, from Fossil Hill, Nevada. The existence of a very distinct carina on the body whorl of *Pompholyx* from Anaho Island, and its absence on recent forms, is still again suggestive of the same genetic relation. Lake Bonneville, in its Lake Utah representative, furnishes an allied fact. *Radix ampla*, var. *utahensis*, presents features allying it to *Polyrhytis kingii* Meek, from the Miocene-Tertiary of Cache Valley, Utah. Thus, in each of these great areas are recent forms of like family relations, but belonging to different genera, related respectively to forms nearly congeneric with them, but of Tertiary age. The differences which they present are certainly less specific than those exhibited in the Tertiary species of *Planorbis* from Steinheim, which have recently formed the subject of an elaborate memoir.[6]

The comparative wealth in genera and species of the areas comprised in Lake Lahontan and Bonneville, as well as the differences and identi-

[5] *Pyrgula scalariformis* Wolf is an apparent exception to this statement, but much doubt attaches to the generic reference of the form so named. It was described from the post-Pliocene of Tazewell Co., Ill., in which a genus—*Pomatiopsis*—sustaining a superficial resemblance to *Pyrgula* is known to occur. Moreover, the correlation of species and station, as above indicated, combined with the sole possible stations of the fossil forms, certifies the doubt.

[6] Hyatt, "On the Tertiary Species of Planorbis at Steinheim." Anniversary Memoirs Boston Society of Natural History, 1880.

ties of their fossil and recent mollusca, is succinctly shown in Table V, following:

TABLE V.—*Distribution of Fresh-water Shells.*

| Family. | Genus. | Species. | Lahontan. | | Bonneville. | |
|---|---|---|---|---|---|---|
| | | | Recent. | Fossil. | Recent. | Fossil. |
| Unionidæ | Margaritana | margaritifera, Linn | * | * | * | |
| | Anodonta | nutalliana, Lea | * | †* | * | † |
| Cyrticulidæ | Sphærium | dentatum, Hald | | * | * | † |
| | | striatinum, Lam | * | * | * | |
| | Pisidium | compressum, Prime | * | * | * | |
| | | abditum, Hald | | | * | |
| Limnæidæ | Helisoma | corpulentus, Say | * | † | | |
| | | ammon, Gould | * | † | | |
| | | trivolvis, Say | * | * | * | * |
| | | subcrenatus, Carp | * | | | |
| | Gyraulus | parvus, Say | * | * | * | † |
| | | vermicularis, Gould | * | * | | |
| | Menetus | opercularis, Gould | * | * | * | |
| | Limnophysa | palustris, Müll | * | †* | * | †* |
| | | sumasai, Baird | * | * | * | † |
| | | humilis, Say | * | * | * | |
| | | bulimoides, Lea | * | † | | |
| | | bonnevillensis, Call | | | | * |
| | Limnæa | stagnalis, Linn | | † | * | † |
| | Radix | ampla, *var.* Utahensis, Call | | | * | |
| | Physa | gyrina, Say | * | | * | |
| | | humerosa, Gould | * | † | | |
| | | ampullacea, Gould | * | | * | |
| | | heterostropha, Say | * | | * | † |
| | | elliptica, Lea | | | * | |
| | | lordi, Baird | | | | † |
| | Pompholyx | effusa, Lea (vars) | * | † | | |
| | Carinifex | newberryi, Lea | | †* | * | |
| | Ancylus | newberryi, Lea | | * | | |
| Bissoidæ | Amnicola | dalli, Call | * | | | |
| | | longinqua, Gould | | * | * | |
| | | porata, Hald | | | | * |
| | | cincinnatiensis, Anth | | | | * |
| | Fluminicola | fusca, Hald | | * | * | †* |
| | Pyrgula | nevadensis, Stearns | * | | | |
| | Bythinella | binneyi, Tryon | | * | | |
| Valvatidæ | Valvata | virens, Tryon | | | * | |
| | | sincera, *var.* utahensis, Call | | | * | † |
| (5) | (19) | 38 | 22 | *18, †8 | 22 | *6, †10 |

NOTE.—The asterisk (*) is used simply to indicate the presence of the species in either the recent or the fossil fauna. The dagger (†) is used to indicate semi-fossils. When the same species is found both fossil and semi-fossil, the signs are written together, with the relative abundance indicated by the order of the signs.

In this table only the fresh-water shells are listed. But, comparing Tables I and III, in which land-forms are included, it will be observed that Lahontan furnishes eighteen genera and twenty-six species, comprised in seven families. Bonneville presents eleven genera and sixteen species, distributed among six families. Only six of the sixteen species are Bonneville fossils, but eight others are semi-fossils in the Bonneville area. Of recent forms, as exhibited in Tables II and IV, the genera are equal in number, but are not all common to the two areas, and include all the known land-shells of the respective regions. Moreover, the Lahontan area furnishes an equal number of families and a greater number of species.

Of the thirty-eight species of freshwater shells, twenty-two are living in the Lahontan area, twenty-two in the Bonneville, and thirty in the entire district; twenty-three are known fossil or semi-fossil in the La-

hontan area, thirteen in the Bonneville, and twenty-eight in the entire district. The Lahontan area includes of living and fossil twenty-six, the Bonneville twenty-four.

It will at once be noted that the majority of fresh-water forms presented alike by all these five tables belong to the *Limnæidæ*. This family is world-wide in distribution, and exhibits a most remarkable group of genera and subgenera in its various divisions. Of all fresh-water forms the species of *Limnæidæ* have the greatest hypsometric range, extend to the highest latitudes, and best survive certain physical changes, such as droughts, extremes of cold, and, as our investigations in the Great Basin prove, even transitions from fresh to saline waters. In the north temperate regions of America some species—*Limnæa stagnalis*, *Bulimnæa megasoma*, *Limnophysa palustris*, *L. sumassi*, and *Physa lordi*—reach a high degree of perfection and appear to be eminently adapted to that habitat. Some of these—*Limnæa stagnalis* and *Limnophysa palustris*—are circumboreal, and find in these latitudes their metropolis. The identity of other American with European forms is highly probable. Such species as are known to be common to Europe find their southernmost range in the Great Basin.

It is, perhaps, fortunate that this widely distributed family is so amply developed within this area. Its range is such that it here finds an almost infinite variety of station,[7] often an environment structurally uncongenial, temperature ranges which may be either above or below its optimum, but which are comprised within wide limits, and, as might be expected, it presents a range of variation clearly co-ordinate with the physical conditions of its environment. Many of the variant features presented are clearly local or accidental; such, for example, as those which arise from distortion,[8] traumatism, and so forth.

Eliminating these features, and those of kindred character and consequences, there yet remain other characters, such as size, color, thickness, and coiling of whorls, entirely dependent upon causes general in respect both to their range of operation and the effects they produce. Of these, one principal factor is food, in its character and abundance. So far as certain genera of *Limnæidæ* furnish reliable data, their station is largely determined by food opportunities. In another great American family, not represented in the Great Basin—the *Strepomatidæ*—the

[7] "Station," as used herein, is to be understood as immediate and permanent physical environment; "habitat" is used in the sense of geographic distribution.

[8] Distortion is often clearly the result of purely local conditions, but even then varieties may be produced that present established features of a specific value in succeeding generations. The Steinheim *Planorbes*, previously cited, present a case in point. Ingersoll has described (in Annual Report of the Hayden Survey, 1874, p. 402, a distorted form of *Helisoma* (*Planorbis*) to which he gives the name *H. plexata*. The shells, which abounded in places where thrived a species of closely matted aquatic plant, came from a lake of considerable elevation (9,500 feet) in Antelope Park, Colorado. The shell was accommodating its growth to the ever-varying conditions of the pond in which it dwelt. In such a case as this the correlation of aberrant forms with their surroundings is comparatively an easy task.

same law holds true. They abound in the southern United States, in clear rocky mountain streams, in those stations suited to the growth of confervæ, and their habitat is clearly connected therewith. The abundance of a species is, in a restricted sense, a measure of suitable food opportunities; and the abundant shell fauna of the dendritic stage of Lahontan is a witness that fresh-water confervæ—the sole food of *Pompholyx*—flourished in great abundance. The wide range of variation seen in the vast numbers of that form from the Lahontan area, under conditions of abundance that lead to the elimination of food as a factor clearly point to some other potent agent, the effects of which are remarkably uniform throughout the area.

## DEPAUPERATION *versus* SALINITY.

Before passing to a consideration of these factors a further remark upon an anomaly in distribution as regards station is necessary. In both the Lahontan and the Bonneville areas fresh-water species occur in brackish-water stations, accommodating themselves to abnormal conditions. In the Lahontan Basin the forms are found solely, as far as information goes, in lacustrine waters. Walker's Lake, quite fresh as compared with Pyramid Lake, has furnished no living shells whatever; but Pyramid Lake, with $\frac{1}{150}$ of saline matter, abounds in the fresh-water *Pyrgula*, and contains also *Pompholyx* and *Physa*. No bivalves of any kind have yet been found in either salt or brackish water. In the Bonneville area the forms occur in brackish springs, but in none of the salt or brackish lakes so far as known. *Limnophysa* and *Physa* are the sole genera, each represented by a single species. The first of these genera has not yet been found in saline stations in the Lahontan area. On the other hand, neither *Pompholyx* nor *Pyrgula* occurs in either fresh or salt waters in the Bonneville Basin. *Physa* alone is common to the fresh and saline stations of the two areas. When *Pompholices*, of the Lahontan area, from fresh-water stations are compared with *Pompholices* from saline stations, the forms are seen to differ in some important particulars. Not only do the fresh-water *Pompholices* grow to a much greater size, but they have thinner and lighter shells. The shape of the apertures presents a wider range of variation in the brackish-water forms, and the epidermis is lighter in color. It is believed that these differences have been successfully correlated with the differences of station—saline or fresh water. In the Bonneville area the minimum of saline matter is found in the brackish springs, but the same biologic features are presented.[9] The shells of *Physa* and *Limnophysa* from

[9] Some of these springs have a chemical constitution that varies within wide limits at different times of the year. In the fall they are brackish, but in the spring fresh and sweet. See Stansbury's "Report on Expedition to Great Salt Lake," p. 174. Whether these are mollusk-bearing is unknown.

such stations are much less dense, the lines of growth are fainter and much closer, and the sculpturing is altogether more variable than in specimens derived from fresh-water streams adjacent.

That the power of accommodation possessed by these shells is not unlimited is sufficiently indicated by their uniform absence from salt marshes and from highly saturated saline lakes.

It is to be regretted that no data bearing on comparative salinity of springs and lakes in which mollusks have been taken living exists. They would surely have proven important aids in this discussion. The tables which follow are such as compare forms taken from fresh water with those known to come from stations of varying degree of salinity.[10] They are useful in establishing the obvious relation existing between the size of the various specimens and their environment. But, assuming that the various degrees of salinity presented by the springs, from fresh-water to that of a percentage incompatible with the life of any limnæid, has been presented by Lake Lahontan since its beginning until now, the ratio of salinity has been and is a variable; as the lake levels rose and fell so did the variable decrease or increase in value. This variable presumably found a biologic expression in the abundance of shell life, as has been above indicated in the case of *Pompholyx*, during the different tufa-forming periods of the lake. Table VI, based upon material from a fresh-water station and from Pyramid Lake, together with its graphic form in Plate II, Diagram I, shows this variable in living *Pompholyx* biologically expressed in difference of size.

TABLE VI.—*Pompholyx effusa* Lea.

| Number. | Pyramid Lake. | | White Pine. | |
|---|---|---|---|---|
| | Height. | Breadth. | Height. | Breadth. |
| | mm. | mm. | mm. | mm. |
| 1 | 4.50 | 5.40 | 5.60 | 6.60 |
| 2 | 4.44 | 5.20 | 6.76 | 8.80 |
| 3 | 4.44 | 4.86 | 7.00 | 8.40 |
| 4 | 4.50 | 5.00 | ..... | ..... |
| 5 | 5.00 | 5.50 | ..... | ..... |
| 6 | 5.78 | 6.00 | ..... | ..... |
| 7 | 4.60 | 5.50 | ..... | ..... |
| 8 | 5.22 | 5.82 | ..... | ..... |
| 9 | 5.12 | 5.20 | ..... | ..... |
| 10 | 5.40 | 5.74 | ..... | ..... |
| 11 | 4.44 | 5.50 | ..... | ..... |
| Average | 4.86− | 5.38+ | 6.45+ | 7.76+ |

[10] The discussion of this factor, salinity, is conspicuously incomplete. It could not be rendered complete in the absence of salinity determinations for the various stations classed as "saline" and "brackish." The following list of salinites is pertinent but partial: Walker's Lake, Nevada, .9618 grams per liter, the average of two analyses by Prof. F. W. Clarke; Pyramid Lake, average of four analyses by Clarke, 2.2463 grams per liter; Great Salt Lake (1868), 118.60 grams per liter (O. D. Allen); Little Gull Lake, in the Mono Valley, California, and Church Lake, near Salt Lake City, Utah, fresh. Pyramid and Walker's Lakes are herein classed as brackish. Salinity is used throughout this discussion, in the absence of an adequate specific term, in the sense of general chemical constitution. The determinations above given include only sodium chloride.

The value of this table would, probably, have been enhanced by a greater number of specimens from the White Pine locality, but, as usually happens, unless the collector use especial care, only the largest and most easily discoverable forms appear, and these were adults. The ratio of heights of the White Pine specimens to the same dimension of Pyramid Lake specimens is $\frac{6.45}{4.86}$, and for breadth $\frac{7.76}{5.89}$, a result clearly connected with station. Both localities present that form known as *Pompholyx effusa*, var. *solida* Dall, but not differing in well-marked particulars from the typical *P. effusa* Lea.

In Table VII are presented a series of measurements of this same species from localities which have been correlated with three different stages of water in Lahontan, in each of which the ratio of salinity differed. Plate II, Diagram II, is based upon this table. During the period of the deposition of the beds at White Terrace the most noticeable effect of environment is expressed in a height of shell which is certainly anomalous. Joined to this, as its consequent, is a far greater convexity of whorl than is shown by any specimens from beds deposited before or since.

TABLE VII.—*Pompholyx effusa* Lea.

| Number. | Anaho Island. | | White Terrace. | | Pyramid Lake. | |
|---|---|---|---|---|---|---|
| | Height. | Breadth. | Height. | Breadth. | Height. | Breadth. |
| | mm. | mm. | mm. | mm. | mm. | mm. |
| 1 | 4.20 | 5.20 | 8.08 | 5.00 | 4.10 | 5.32 |
| 2 | 3.50 | 4.44 | 8.10 | 6.40 | 5.86 | 6.28 |
| 3 | 3.96 | 5.16 | 7.40 | 5.50 | 6.36 | 5.84 |
| 4 | 3.76 | 4.86 | 6.64 | 5.00 | 5.50 | 7.04 |
| 5 | 4.62 | 6.16 | 8.90 | 5.50 | 5.36 | 6.66 |
| 6 | 3.68 | 4.86 | 6.80 | 4.86 | 6.50 | 7.40 |
| 7 | 3.28 | 4.92 | 8.50 | 5.28 | 5.88 | 6.60 |
| 8 | 4.24 | 5.44 | 7.36 | 5.40 | 7.36 | 6.10 |
| 9 | 3.50 | 5.50 | 6.86 | 5.00 | 5.98 | 7.10 |
| 10 | 2.88 | 4.30 | 7.32 | 5.00 | 5.68 | 6.62 |
| 11 | ..... | ..... | 7.00 | 5.10 | 5.70 | 6.98 |
| 12 | ..... | ..... | 5.50 | 4.42 | 5.26 | 5.83 |
| 13 | ..... | ..... | 6.50 | 4.50 | 5.60 | 6.80 |
| 14 | ..... | ..... | ..... | ..... | 7.70 | 8.36 |
| 15 | ..... | ..... | ..... | ..... | 5.22 | 6.32 |
| 16 | ..... | ..... | ..... | ..... | 5.34 | 6.42 |
| 17 | ..... | ..... | ..... | ..... | 5.28 | 6.72 |
| 18 | ..... | ..... | ..... | ..... | 5.12 | 6.04 |
| 19 | ..... | ..... | ..... | ..... | 4.10 | 5.56 |
| 20 | ..... | ..... | ..... | ..... | 5.48 | 6.66 |
| 21 | ..... | ..... | ..... | ..... | 5.00 | 6.30 |
| 22 | ..... | ..... | ..... | ..... | 4.88 | 5.82 |
| 23 | ..... | ..... | ..... | ..... | 5.14 | 6.16 |
| 24 | ..... | ..... | ..... | ..... | 5.30 | 6.18 |
| 25 | ..... | ..... | ..... | ..... | 6.00 | 7.04 |
| Average | 3.76+ | 5.23+ | 7.30 | 5.15 | 5.43— | 6.28+ |

Evidence of a similar character is presented by Table VIII, graphically represented in Plate III, Diagram I. The measurements in this instance are based upon specimens of *Carinifex* from two localities, the deposits of which, though derived from different lakes, were both late Quaternary and may have been contemporaneous. Those from the south end of Winnemucca Lake are from beds deposited at approximately the same date as the lake beds at White Terrace, the locality used in the construction of Table VII. Those from Christmas Lake

were found on the surface of a plain in company with the bones of extinct mammals. The ratio of size for the Winnemucca fossils, as compared with the Oregon shells, is, for height $\frac{10.26}{8.79}$, and for breadth $\frac{11.58}{10.03}$.

TABLE VIII.—*Carinifex newberryi* Lea.

| Number. | Winnemucca Lake (fossil). | | Christmas Lake. | |
|---|---|---|---|---|
| | Height. | Breadth. | Height. | Breadth. |
| | mm. | mm. | mm. | mm. |
| 1 | 8.54 | 10.50 | 8.53 | 10.20 |
| 2 | 11.50 | 11.68 | 8.00 | 10.48 |
| 3 | 11.26 | 11.78 | 7.50 | 9.32 |
| 4 | 10.10 | 13.10 | 9.50 | 10.10 |
| 5 | 11.22 | 12.76 | 9.00 | 11.00 |
| 6 | 10.18 | 11.74 | 10.30 | 10.10 |
| 7 | 9.00 | 9.50 | 9.20 | 9.20 |
| 8 | ..... | ..... | 8.50 | 10.52 |
| 9 | ..... | ..... | 8.50 | 9.24 |
| Average | 10.26 | 11.58 | 8.79+ | 10.03 |

In the Bonneville Basin similar results are exhibited by the measurements of shells obtained from brackish springs. In some cases comparisons have been instituted between shells collected in contiguous areas, thus insuring equal climatal conditions, but in other cases between shells from regions more remote. Thus in Table IX, upon which is based Plate III, Diagram II, specimens found fossil, lying upon the surface of the desert east of south Carson Lake, Nevada, are compared with specimens of the same species from Warm Spring Lake, Utah. The ratio of size is nearly as 1 to 2; but, as will appear below, the Utah specimens were specially favored by another factor, of climatal nature. The smallest of the Warm Spring Lake specimens is far above the largest of the Carson Desert forms.

TABLE IX.—*Helisoma trivolvis* Say.

| Number. | Carson Lake Desert. | | Warm Spring Lake. | |
|---|---|---|---|---|
| | Height. | Breadth. | Height. | Breadth. |
| | mm. | mm. | mm. | mm. |
| 1 | 7.00 | 13.00 | 11.00 | 21.10 |
| 2 | 6.90 | 12.20 | 10.80 | 19.80 |
| 3 | 8.24 | 15.58 | 11.80 | 25.10 |
| 4 | 7.32 | 11.64 | 11.00 | 20.26 |
| 5 | 6.50 | 7.12 | 10.44 | 21.84 |
| 6 | 6.84 | 14.60 | 10.82 | 20.00 |
| 7 | 7.50 | 9.60 | 10.64 | 19.00 |
| 8 | 6.56 | 12.86 | 11.24 | 21.12 |
| 9 | 5.90 | 11.00 | 10.32 | 22.08 |
| 10 | 5.88 | 9.60 | 11.54 | 19.80 |
| 11 | 6.10 | 11.00 | 12.38 | 25.38 |
| 12 | 6.20 | 11.70 | 11.50 | 25.76 |
| 13 | ..... | ..... | 10.88 | 17.60 |
| 14 | ..... | ..... | 10.74 | 22.00 |
| 15 | ..... | ..... | 10.50 | 25.50 |
| 16 | ..... | ..... | 10.16 | 19.64 |
| 17 | ..... | ..... | 10.94 | 21.60 |
| 18 | ..... | ..... | 11.50 | 22.20 |
| 19 | ..... | ..... | 11.06 | 23.10 |
| 20 | ..... | ..... | 10.26 | 21.42 |
| 21 | ..... | ..... | 11.06 | 24.00 |
| 22 | ..... | ..... | 11.96 | 25.90 |
| Average | 6.74+ | 11.66— | 11.00+ | 21.87+ |

No lakes of the Bonneville area, except those entirely fresh, are known to be mollusk-bearing. Moreover, there have been found no fossil shells ranging in point of time, throughout the Bonneville beds upon which to base any conclusion, as in the case of Lahontan, concerning the effect of any degree of salinity upon them, if they existed. But a similar line of corroborative evidence is presented by the shells from brackish springs. Upon such material have been based Tables X and XI, and Plate IV, Diagrams I and II. Here again, in the case of Warm Spring Lake, the climatal factor is brought out prominently. In these tables are exhibited similar results, seen by comparing the averages in the case of two new genera not known in the saline waters of the Lahontan area, but subjected to environmental conditions similar to those of *Pompholyx*. The physiologic effects of the similar stations are identical.

TABLE X.—*Limnophysa palustris* Müll.

| Number. | Honey Lake. | | Warm Spa Lake. | | Brackish Springs (Promontory). | |
|---|---|---|---|---|---|---|
| | Length. | Breadth. | Length. | Breadth. | Length. | Breadth. |
| | mm. mm. | mm. mm. | mm. mm. | mm. mm. | mm. mm. | mm. mm. |
| 1 | 29.50 | 9.90 | 18.50 | 7.32 | 16.50 | 7.30 |
| 2 | 28.20 | 9.50 | 23.04 | 9.14 | 25.46 | 10.74 |
| 3 | 24.80 | 9.80 | 24.08 | 10.06 | 19.00 | 7.72 |
| 4 | 23.16 | 9.80 | 19.00 | 9.54 | 22.12 | 9.50 |
| 5 | 26.50 | 11.20 | 27.16 | 11.64 | 21.10 | 8.40 |
| 6 | 25.70 | 10.22 | 26.50 | 11.58 | 18.90 | 8.70 |
| 7 | 25.20 | 10.90 | 25.20 | 11.60 | 22.36 | 8.80 |
| 8 | 25.12 | 9.90 | 26.80 | 11.32 | 26.10 | 10.12 |
| 9 | 24.50 | 9.80 | 29.00 | 11.70 | 16.80 | 7.60 |
| 10 | 30.40 | 11.50 | 28.04 | 12.16 | 14.34 | 6.94 |
| 11 | 19.70 | 8.70 | 28.48 | 12.40 | 16.86 | 7.08 |
| 12 | 23.20 | 10.00 | 23.38 | 9.64 | 16.34 | 7.42 |
| 13 | 26.00 | 9.60 | 27.00 | 11.92 | 15.50 | 6.70 |
| 14 | 17.80 | 7.12 | 24.50 | 10.48 | 19.06 | 9.00 |
| 15 | 17.00 | 7.50 | 26.50 | 11.40 | 19.00 | 8.20 |
| 16 | 21.00 | 8.30 | 20.40 | 8.24 | 22.30 | 8.92 |
| 17 | 19.50 | 7.10 | 25.70 | 11.30 | 22.24 | 9.20 |
| 18 | 20.50 | 8.52 | 23.70 | 10.06 | 15.60 | 6.68 |
| 19 | | | 29.24 | 12.24 | 18.78 | 8.04 |
| 20 | | | 25.70 | 9.44 | 16.32 | 8.72 |
| 21 | | | 26.10 | 10.56 | 21.44 | 10.00 |
| 22 | | | 27.52 | 11.76 | 19.28 | 9.22 |
| 23 | | | 29.42 | 11.50 | 21.88 | 9.50 |
| 24 | | | 29.88 | 12.04 | 25.62 | 10.90 |
| 25 | | | 33.10 | 13.50 | | |
| Average | 23.28+ | 9.38+ | 25.82+ | 10.92+ | 19.40+ | 8.50+ |

TABLE XI.—*Physa gyrina* Say.

| Number. | Salt Lake City (ponds). | | Promontory (Brackish Springs). | |
|---|---|---|---|---|
| | Length. | Breadth. | Length. | Breadth. |
| | mm. | mm. | mm. | mm. |
| 1 | 18.96 | 9.86 | 13.30 | 6.30 |
| 2 | 20.32 | 11.58 | 14.24 | 7.48 |
| 3 | 19.00 | 10.42 | 15.00 | 6.88 |
| 4 | 19.24 | 10.50 | 14.32 | 6.74 |
| 5 | 16.50 | 9.12 | 17.60 | 8.52 |
| 6 | 16.34 | 9.70 | 16.12 | 7.70 |
| 7 | 18.50 | 10.50 | 16.00 | 7.64 |

TABLE XI.—*Physa gyrina* Say—Continued.

| Number. | Salt Lake City (ponds). | | Promontory (Brackish Springs). | |
|---|---|---|---|---|
| | Length. | Breadth. | Length. | Breadth. |
| | mm. | mm. | mm. | mm. |
| | 16.28 | 9.50 | 14.74 | 7.20 |
| | 19.26 | 10.90 | 13.64 | 7.00 |
| | 17.80 | 9.88 | 13.00 | 6.16 |
| | 22.70 | 13.26 | 18.08 | 9.04 |
| | 18.24 | 11.00 | 18.74 | 8.38 |
| | 19.00 | 11.16 | 13.84 | 6.62 |
| | | | 17.34 | 8.40 |
| | | | 17.94 | 8.60 |
| | | | 18.44 | 8.00 |
| | | | 20.64 | 9.14 |
| | | | 18.96 | 9.40 |
| | | | 20.70 | 9.48 |
| | | | 21.20 | 9.12 |
| | | | 21.82 | 9.74 |
| | | | 18.76 | 9.16 |
| | | | 17.28 | 7.88 |
| | | | 14.42 | 7.04 |
| | | | 16.80 | 7.40 |
| | | | 15.60 | 7.50 |
| | | | 15.82 | 7.10 |
| | | | 16.32 | 7.00 |
| | | | 13.80 | 6.88 |
| | | | 18.56 | 8.16 |
| | | | 20.70 | 8.88 |
| | | | 18.50 | 9.30 |
| | | | 15.60 | 7.46 |
| | | | 16.20 | 7.20 |
| | | | 20.50 | 9.50 |
| | | | 21.84 | 9.50 |
| | | | 17.32 | 7.30 |
| | | | 15.80 | 6.80 |
| | | | 15.50 | 7.78 |
| rage | 18.55— | 10.57— | 16.69 | 7.90 |

ly summarized the results of the measurements are as follows.
, the size (linear) of *Pompholyx effusa* in brackish water (Pyra-ake) is to its size in fresh water (White Pine) as 72 to 100. The *Limnophysa palustris* in brackish springs (Promontory) is to its fresh water (Honey Lake) as 85 to 100. The size of *Physa gyrina* kish springs (Promontory) is to its size in fresh ponds (Salt ity) as 84 to 100. Brackish water is thus correlated with depau-n.

nd, comparing *Pompholyx effusa* from Anaho Island (Lower La-), White Terrace (Upper Lahontan), and White Pine (recent), the size is 63: 88: 100. The size ratio for *Helisoma trivolvis* from Desert (semi-fossil) and Warm Spring Lake (recent) is 56: 100, s is affected by the exceptional warmth of the latter locality. ieck recent specimens of *Limnophysa palustris* from Honey Lake arm Spring Lake are compared, yielding a size ratio 89: 100. peration is thus correlated with the Quaternary conditions.

physiologic effects of sudden introduction of marine mollusks sh water, or of fresh-water forms into strongly saline waters, are r. The result in either case is the death of the shells so treated.

But the shock produced by sudden transfer may be measurably avoided by a gradual change in the salinity or freshness of the water.

On this point Beudant long since conducted some valuable experiments, the results of which have been tabulated, as follows, by Semper:[11]

TABLE XII.—*Experiments with Fresh-water Mollusca.*

| Names of species. | Number in the first instance, on May 1. | Number on July 15. | | Number on October 15. | |
|---|---|---|---|---|---|
| | | In fresh water. | In salt water of 2 per cent. | In fresh water. | In salt water of 4 per cent. after 17 days. |
| Limnæa stagnalis | 80 | 21 | 23 | 16 | 13 |
| Limnæa auricularis | 80 | 19 | 17 | 14 | 11 |
| Limnæa palustris | 50 | 33 | 27 | 22 | 19 |
| Physa fontinalis | 50 | 28 | 27 | 17 | 21 |
| Planorbis corneus | 80 | 22 | 19 | 15 | 13 |
| Planorbis carinatus | 50 | 24 | 31 | 19 | 16 |
| Planorbis vortex | 50 | 37 | 29 | 26 | 22 |
| Ancylus lacustris | 50 | 39 | 33 | 28 | 25 |
| Paludina vivipara | 80 | 23 | 24 | 21 | 11 |
| Paludina tentaculata | 50 | 38 | 35 | 31 | 17 |
| Paludina obtusa | 60 | 42 | 39 | 37 | 30 |
| Neritina fluviatilis | 50 | 37 | 31 | 26 | 9 |
| Unio pictorum | 20 | 17 | 13 | 8 | ..... |
| Anodonta cygnea | 15 | 11 | 10 | 7 | ..... |
| Cyclas cornea | 40 | 32 | 25 | 18 | ..... |

TABLE XIII.—*Experiments with Marine Mollusca.*

| Names of species. | Number in the first instance, on January 1. | Number on June 1. | | Number on September 15. | |
|---|---|---|---|---|---|
| | | In sea water. | In half fresh water. | In sea water. | In quite fresh water after fifteen days. |
| Patella vulgata | 30 | 23 | 21 | 16 | 15 |
| Turbo neritoides | 50 | 39 | 37 | 22 | 25 |
| Purpura lapillus | 30 | 28 | 26 | 19 | 17 |
| Arca barbata | 30 | 28 | 22 | 17 | 18 |
| Venus maculata | 30 | 26 | 23 | 18 | 15 |
| Cardium edule | 30 | 25 | 21 | 17 | 15 |
| Ostrea edulis | 15 | 15 | 13 | 14 | 11 |
| Mytilus edulis | 30 | 30 | 30 | 30 | 26 |
| Balanus striatus | 21 | 19 | 21 | 18 | 19 |
| Fissurella unciposa | 30 | 21 | 18 | 14 | ..... |
| Haliotis tuberculata | 15 | 13 | 11 | 5 | ..... |
| Buccinum undatum | 20 | 17 | 13 | 11 | ..... |
| Tellina incarnata | 30 | 24 | 21 | 13 | ..... |
| Pecten varius | 20 | 19 | 7 | 11 | ..... |
| Chama lazarus | 10 | 9 | 5 | 8 | ..... |

In the first place, experiments were conducted with reference to the physiologic effect of sudden transition from fresh to salt water. Subsequently, at Marseilles, the reverse experiment was tried, and numer-

[11] *Vide* Animal Life, 1881, p. 439.

ous specimens of Mediterranean mollusca were suddenly transferred to fresh water. In both cases the experiments were repeatedly varied, until finally the results set forth in these tables were exhibited. It is, however, to be observed that marked increase in salinity eventually produced, in some instances, a result similar to sudden transfer. At the end of the experiments none of the fresh-water Lamellibranchiata were living, while the *Limnæidæ* were, on the whole, well represented. The experiments began on May 1 and terminated October 15. At the commencement 340 specimens of various limnæid genera were placed in fresh water, the salinity of which was gradually increased from 0 to 4 per cent. There were then living 140 individuals, or little more than 41 per cent. of the whole. Of the 15 species, belonging to as many genera, of marine shells with which he subsequently experimented, commencing with January 1 and concluding September 15 following, 6 had no survivor after 15 days in water which was quite fresh. Of the whole number of specimens, 391, little more than 42 per cent., 165, were living. One genus—*Mytilus*—represented by 30 individuals, had survived in undiminished numbers. Its power of endurance is seen, consequently, to be unusually great.

Notwithstanding several months intervened between the beginning and end of Beudant's experiments, it remains to be noted that these conditions were produced by him within a period which, compared to the time required to produce in Lake Lahontan exactly equivalent conditions, was infinitesimally small. The artificial introduction of small quantities of salt, or of salt water, in order to induce desired changes in environment, could proceed with something like regularity, but in the great body of water composing Lahontan or Bonneville, the same result could be reached only through evaporation, a process extending through long periods of time, during which climatal changes frequently intervened to freshen the gradually contracting lake. The full biologic expression of these changes could, therefore, only be sought in generations widely separated in point of time. During their march each succeeding generation must have acquired something of the power of resistance developed by its ancestry. But whatever of vital force was abstracted from the general organism to offer protective aid to the maintenance of life, as against the new unfavorable element in environment, must have deprived some other specialized organs of full power to exercise their functions. With this transfer of vital energy, we believe, came its biologic expression—depauperation.

The final result of Beudant's experiments, in which he had marine and fresh-water mollusca living together in fresh water, was a condition which held true for certain portions of the ancient Laramie Sea of North America. From strata of Laramie age are described many marine and fresh-water species so associated as to necessitate the conclusion that they were co-existent. In these beds are found several species of *Unionidæ* genetically related to various species now found in the

Mississippi Basin.[12] *Unio* is very susceptible to changes in environment, and appears to respond to them with extreme rapidity. Nevertheless certain species live in brackish water, as seen in the Brisbane River, in eastern Australia, where *Unio* is found in stations the freshness of which is solely dependent upon the heights and times of tides. In the Livonian Gulf, *Cyclas*, *Unio*, and *Anodonta* live associated with *Tellina* and *Venus*. Many species of *Neritina* inhabit alike brackish and salt water, especially in the Philippines.[13] In the Laramie strata are found examples of the *Strepomatidæ*, the specimens ranking under the genus *Goniobasis*, now exclusively confined to waters entirely fresh, and not found in waters close to the sea, even when abounding in the upper portions of many Atlantic rivers. While a full discussion of these and allied facts is here impracticable, sufficient data are presented to justify the hypothesis that increase in salinity finds a biologic expression (*a*) in depauperation, (*b*) in lessened abundance, and (*c*) in extinction when the water becomes briny.

## DEPAUPERATION *versus* TEMPERATURE.

There is a second factor entering into the solution of the problem presented by the fossils studied. This second factor, like the first, is a variable, but, unlike the first, reaches its extremes in far less periods of time. This factor is temperature. Gilbert has shown[14] that Lake Bonneville is the expression of a climatal episode consisting of two humid maxima, and, reasoning by analogy, has correlated its varying stages with a variable precipitation intimately connected with the temperature changes of the Quaternary and its great ice-fields. In Lahontan a similar history is exhibited by the investigations of Russell,[15] and if the Lahontan tufa epochs have been correctly correlated with humidity epochs, it is also expressed by the varying abundance of *Pompholyx*, as above indicated. In Bonneville no series of fossils, correlated with its varying stages, have been found, the characteristic fossils, *Amnicola porata* and *A. cincinnatiensis*, being found only in beds of Upper Bonneville age, and are not known to be living within the area.

The minimum temperature to which certain limnæid forms may be subjected, and survive, is remarkable. *Limnæa stagnalis* has been actually frozen, but revived again on increase of temperature. A similar condition, or a nearly similar one, is annually produced in shallow ponds and ditches within the more northern United States, but every spring

[12] See White on "Antiquity of certain Subordinate Types of Fresh-water and Land Mollusca." Am. Jour. Sci., 1880, Vol. XX, 44.

See also "Non-marine Fossil Mollusca of North America." Third Ann. Report U. S. Geological Survey, pp. 472–477, 1881–'82. Also issued separately.

[13] *Vide* Animal Life, Semper, pp. 434–435, for authorities.

[14] In Second Annual Report of the U. S. Geological Survey, "Contributions to the History of Lake Bonneville."

[15] Third Annual Report U. S. Geological Survey, "On Lake Lahontan," pp. 195–235.

they again teem with the old shells of the preceding years. It is matter of common observation, despite the pulmonate character of the family, to see *Physa* and *Limnophysa* crawling upon the bottom of ponds wholly frozen over.[16] The principal effect of a lowering of temperature is complete or partial loss of power of assimilation, expressed by checks in growth. The lowest thermometric range compatible with assimilation in *Limnæa stagnalis* was found by Semper[17] to be 12° C. Chill-coma results whenever the temperature falls below a certain critical point, which varies considerably for different forms. The optimum temperature range for most fresh-water mollusca is small, but greater for the *Limnæidæ* than for any other family. The biologic expression of this law over wide latitudes is obvious in the varying abundance and size of the different forms; and analogy warrants the assumption that it holds true for hypsometric distribution also. But it is not necessary to depend altogether on analogy, for there have been placed in my hands series of shells from springs of wide range of temperature and also from lakes and ponds of varying altitudes. Table XIV, together with Plate V, Diagram I, is based upon shells from localities of widely varying altitudes.

TABLE XIV.—*Physa ampullacea* Gould.

| Number. | Little Gull Lake. | | Church Lake. | |
|---|---|---|---|---|
| | Length. | Breadth. | Length. | Breadth. |
| | mm. | mm. | mm. | mm. |
| 1 | 11.44 | 6.40 | 14.18 | 9.16 |
| 2 | 12.50 | 9.10 | 16.16 | 10.60 |
| 3 | 11.82 | 7.00 | 18.08 | 11.58 |
| 4 | 12.20 | 8.00 | 17.84 | 10.62 |
| 5 | 13.72 | 8.88 | 16.22 | 10.60 |
| 6 | 13.22 | 9.20 | 15.00 | 10.24 |
| 7 | 10.30 | 6.36 | 14.34 | 9.44 |
| 8 | 13.00 | 9.32 | 14.80 | 10.96 |
| 9 | 12.60 | 8.62 | 15.50 | 10.50 |
| 10 | 13.76 | 8.50 | 14.96 | 9.24 |
| 11 | 16.10 | 10.20 | 12.62 | 8.80 |
| 12 | 15.00 | 9.44 | 16.40 | 10.70 |
| 13 | ..... | ..... | 13.38 | 8.58 |
| 14 | ..... | ..... | 14.00 | 9.18 |
| 15 | ..... | ..... | 13.60 | 9.24 |
| 16 | ..... | ..... | 12.06 | 8.12 |
| 17 | ..... | ..... | 14.72 | 8.98 |
| 18 | ..... | ..... | 16.20 | 10.04 |
| Average | 12.97 | 8.45 | 14.98 | 9.81 |

*Planorbis*, *Limnophysa*, and *Physa*, from Little Gull and Parker's Lakes in the Mono Basin, California, at an elevation of from 7,000 to 7,500 feet, present variant features clearly connected with station. The shells are exceedingly light and fragile, and below the normal size of fully

[16] The writer has also collected living *Unio ventricosus*, *U. luteolus*, and *U. rubiginosus* in the Des Moines River, Iowa, at Des Moines, in January, 1882. They were taken from shallow water over a bar, the ice reaching nearly to the bottom.

[17] *Loc. cit.*, p. 108.

developed adults.[18] Parker's Lake is especially cold, because snow-fed; but since the most extensive series come from Little Gull Lake, measurements based upon specimens from it are alone presented. Compared with the same species from Church Lake, near Salt Lake City, Utah, with an altitude of about 4,300 feet, the average size is seen to be much less. The ratio of lengths is $\frac{14.26}{12.19}$, and the ratio of widths $\frac{9.61}{8.48}$. Referring again to Tables IX and X, pages 33 and 34, containing the measurements for *Helisoma trivolvis* and *Limnophysa palustris*, additional evidence of a kindred nature is exhibited. In the case of the Warm Spring Lake specimens, particularly, is to be seen the effect of a higher temperature, for the annual mean of a small lake fed by warm springs must be always quite above the minimum essential for assimilation. The process of growth, under such favorable conditions, is either extended over greater periods of time or proceeds more rapidly during its continuance. This would appear to be almost the sole explanation of the gigantic proportions exhibited by the Warm Spring Lake specimens.

A similar effect has been noticed in *Goniobasis carinifera* and *Goniobasis bella*, both being species which abound in the brooks and springs of the northern portions of Georgia and Alabama. Often, within a few feet of each other—the one station a spring, the other a brook—the difference in size is marked. Some observations made by Mr. T. H. Aldrich, in north Alabama, seem to indicate that in springs this genus does not hibernate as it does in brooks and rivers. The only assignable reason appears to be that the mean temperature of such springs does not widely vary.[19]

In only one instance has it been possible to make comparative measurements of fossils from the Bonneville area; but in that case they are based upon a species now existing under circumstances quite different from those which probably completed the environment of the fossils while living. Table XVI, upon which is based Plate V, Diagram II, presents the results. The fossils are of Upper Bonneville age, and from beds correlated with a high stage of water, and hence of increased precipitation, the climatologic bearing of which has been above noted. The mean annual temperature of Utah Lake must be somewhat higher than that of the snow-fed Ogden River; and, moreover, the lake presents the additional favorable feature of quiet water. The average of the Ogden River specimens is below that of those from the lake, while the fossils fall below both, though the fossils must have enjoyed prac-

[18]To what extent this is due to the sum of unequal conditions—*e. g.*, atmospheric pressure combined with lower temperature—it is impossible to state. Whether such low organisms would respond, noticeably, to differences of barometric pressure, is doubtful. Decrease of temperature is positively known to cause depauperation in some forms, and is here assumed to be the chief factor.

[19]On this point there is very little known. So, too, of the shell fauna of thermal springs. The existing data, which appear to have been exhausted by Dr. A. C. Peale (in the Twelfth Annual Report of the Hayden Survey, pt. ii, pp. 358, 359), bear mainly upon vegetable forms, and in no case upon shells.

tically the same favorable conditions of volume, quietness, and food as do now their recent congeners in the lake.

TABLE XVI.—*Fluminicola fusca* Haldeman.

| Number. | Utah Lake. | | Ogden River. | | Bonneville fossils. | |
|---|---|---|---|---|---|---|
| | Length. | Breadth. | Length. | Breadth. | Length. | Breadth. |
| | mm. | mm. | mm. | mm. | mm. | mm. |
| 1 | 12.50 | 8.10 | 10.80 | 6.60 | 8.10 | 5.50 |
| 2 | 11.80 | 7.64 | 9.36 | 7.00 | 9.94 | 6.62 |
| 3 | 10.50 | 6.40 | 9.00 | 6.62 | 9.00 | 5.56 |
| 4 | 11.72 | 7.14 | 8.76 | 7.10 | 7.96 | 6.50 |
| 5 | 10.10 | 7.00 | 9.84 | 6.68 | 7.58 | 5.40 |
| 6 | 10.22 | 6.90 | 9.80 | 6.54 | 7.80 | 6.20 |
| 7 | 10.00 | 7.24 | 9.86 | 7.10 | 9.50 | 6.40 |
| 8 | 9.70 | 6.52 | 10.82 | 6.90 | 8.34 | 5.22 |
| 9 | 10.50 | 6.52 | 8.68 | 6.00 | 7.94 | 5.50 |
| 10 | 11.50 | 8.00 | 8.70 | 5.64 | 8.20 | 5.32 |
| 11 | 9.52 | 7.00 | 9.54 | 6.80 | 8.10 | 5.08 |
| 12 | 9.70 | 6.72 | 8.64 | 5.68 | 8.50 | 5.56 |
| 13 | 12.00 | 7.80 | 8.12 | 5.82 | 7.60 | 5.00 |
| 14 | 10.24 | 6.50 | 8.94 | 6.16 | 8.36 | 5.70 |
| 15 | 10.80 | 8.00 | 9.60 | 6.50 | 8.44 | 5.60 |
| 16 | 10.50 | 6.70 | 8.34 | 6.36 | 9.10 | 5.50 |
| 17 | 11.90 | 8.20 | 8.70 | 5.60 | 8.08 | 5.28 |
| 18 | 11.00 | 7.70 | 8.64 | 6.16 | 7.82 | 5.40 |
| 19 | ..... | ..... | 8.90 | 6.40 | 7.72 | 5.38 |
| 20 | ..... | ..... | 9.88 | 6.30 | 8.00 | 5.34 |
| 21 | ..... | ..... | 9.78 | [illegible] | 8.30 | 6.10 |
| 22 | ..... | ..... | 9.56 | [illegible] | 8.06 | 5.56 |
| 23 | ..... | ..... | 8.80 | 6.00 | 7.24 | 4.98 |
| 24 | ..... | ..... | 9.26 | 6.12 | 8.30 | 5.54 |
| 25 | ..... | ..... | 9.04 | 6.00 | 7.46 | 5.32 |
| Average | 10.76+ | 7.21+ | 9.24 | 6.38 | 8.23 | 5.50 |

## HYPSOMETRIC DISTRIBUTION.

Hypsometric distribution has received from conchologists much less attention than it apparently deserves. Within small areas, comparatively, there are presented by hypsometry those various physical conditions that must otherwise be sought through several degrees of latitude. In this connection no extended careful investigations have been made to ascertain the physical conditions of the extreme heights at which some of our mollusca have been found. But, reasoning from analogy with plants and insects, the minimum of favorable conditions should obtain at great heights, and indeed that general fact is sufficiently indicated by the paucity of genera, species, and individuals at high stations. In France, however, an attempt in this direction has been made by Fischer.[20] He discovers that the terrestrial mollusca of the Pyrenees and Alps, following the analogy of plants, thrive best at certain heights, and each species extends to an altitude beyond the upper limit of which it does not usually pass. The accompanying Table XVII is based upon his

[20] *Comptes Rendus.* Tome 81, p. 624–626, 1875.

results, in which the names of the zones as he originally applied them are retained:

TABLE XVII.—*Hypsometric Distribution of European Mollusca.*[21]

| Zones. | Pyrénées. Name. | No. of genera. | No. of species. | Alpes. Name. | No. of genera. | No. of species. |
|---|---|---|---|---|---|---|
| I ZONE. | *Basses vallées. Limite supérieure, 1,000 mètres.—Zone de l'Helix carthusiana.* | | | *Basses vallées. Limite supérieure, 1,000 mètres.—Zone de l'Helix carthusiana.* | | |
| | *Helix carthusiana*, H. variabilis, *Cyclostoma elegans* | 2 | 3 | Succinea putris, S. oblonga, *Helix carthusiana*, H. fruticum, H. personata, *Cyclostoma elegans* | 3 | 6 |
| | Mollusques fluviatiles: Neritina, Physa, Planorbis, Valvata, Paludina, Bithynia, Sphærium, Unio, Anodonta | 9 | ..... | Mollusques fluviatiles: Physa, Planorbis, Paludina, Bithynia, Sphærium, Unio, Anodonta | 7 | ..... |
| II ZONE. | *De 1,000 à 1,200 mètres.—Zone de l'Helix aspersa.* | | | *De 1,000 à 1,200 mètres.—Zone de l'Helix obvoluta.* | | |
| | Limax maximus, *Succinea arenaria*, Helix aspersa, *H. lapicida*, Pupa farinesi, P. umbilicata | 4 | 6 | *Succinea arenaria*, Helix obvoluta, H. montana, H. incarnata | 2 | 4 |
| III ZONE. | *De 1,200 à 1,500 mètres—Zone de l'Helix limbata.* | | | *De 1,200 à 1,500 mètres.—Zone de l'Helix fontenillei.* | | |
| | Limax marginatus, Zonites cellarius, *Z. fulvus*, Helix limbata, *H. hispida*, Bulimus obscurus, Clausilia abietina | 5 | 7 | Zonites crystallinus, *Helix ericetorum*, H. fontenillei, *H. lapicida*, H. pulchella | 2 | 5 |
| IV ZONE. | *De 1,500 à 2,000 mètres.—Zone de l'Helix nemoralis.* | | | *De 1,500 à 2,000 mètres.—Zone de l'Helix sylvatica.* | | |
| | Arion empiricorum, Limax agrestis, var. sylvatica, Helix nemoralis, *H. rupestris*, *H. ericetorum*, *H. rotundata*, *Clausilia dubia*, Pupa marginata, Pupa megacheilos, Pomatia partioti | 6 | 10 | *Zonites fulvus*, Helix sylvatica, *H. rupestris*, *H. rotundata*, H. ruderata, *H. hispida*, H. ciliata, H. edentula, H. holosericea, H. alpina, H. pomatia, *Clausilia dubia* | 3 | 12 |
| | Mollusques fluviatiles: Ancylus fluviatilis, var. capuloidea | 1 | 1 | | | |
| V ZONE. | *De 2,000 à 2,500 mètres.—Zone de l'Helix carascalensis.* | | | *De 2,000 à 2,500 mètres.—Zone de l'Helix glacialis.* | | |
| | Helix carascalensis, H. rubigena. | 1 | 2 | Vitrina glacialis, V. pellucida, V. nivalis, Zonites petronella, Helix glacialis, H. zonata, H. arbustorum var. alpestris | 3 | 7 |
| | Mollusques fluviatiles: Limnæa limosa var. glacialis | 1 | 1 | | | |

[21] This table is a modification of that employed by Fischer, *loc. cit.* Species common to each area are indicated by *italics*.

The comparatively low altitude at which certain fresh-water genera occur is suggestive to students of Quaternary geology, and, indeed, of older strata in which *Unio*, *Anodonta*, and *Sphærium* occur, as indicating a probable low elevation for the waters in which they lived. To what extent this inference is applicable to the Laramie beds would be a worthy object of inquiry. The high altitudes at which representatives of the *Limnæidæ* occurred, being found in the highest zone in the Pyrenees, is exactly paralleled in the Rocky Mountains and the Sierra Nevada, within the limits of the United States, and in Lake Titicaca and some other bodies of fresh water at great heights in the Andes.

Among land shells in North America the representatives of extreme hypsometric range are *Pupa alticola* and *Vallonia pulchella*—the last being circumpolar.

The same conditions and results should not be sought within areas bounded by isotherms which may approximately represent the maximum or minimum temperatures between which, for any given species, the process of assimilation is continued, for no such inference can be safely drawn from isothermal lines, inasmuch as they mark the mean of often great extremes, either of which would prove fatal to many classes of mollusks and affect all. The mean of temperature does not primarily affect animal life, but great variations and extremes do sensibly modify it. Thus, the transverse irregularly distant lines or ridges in many mollusks, called lines of growth, indicate the cessation and subsequent recommencement of the process of assimilation—a physiologic function dependent very greatly upon climate. In our climate most shells, land and fresh water alike, hibernate during the lower temperature of winter, the period of harmful minimum temperature. Immediately following hibernation comes a period of most rapid assimilation and consequently of growth. This alternation continues during the life of the individual. But in stations where the water is below the optimum temperature, as in Little Gull Lake, Parker's Lake, and other similarly elevated bodies of water, much of the shell-forming energy is diverted to other uses, and there results a shell of great comparative lightness, akin to that seen in shells from stations deficient in calcic carbonate. The constant recurrence of this feature in shells obtained from such stations justifies the hypothesis that here depauperation is the consequent of a temperature below the optimum.

## CONCLUSIONS.

Briefly summarized, the results reached by this study of the fossil and recent shells of the Great Basin are—

(1) That the recent and the fossil mollusca are predominantly limnæid, a biologic expression of climate.

(2) That (*a*) the fossil fauna is more variable than the recent; (*b*) in the Lahontan area being characteristically limnæid (represented by *Pompholyx effusa*), and (*c*) in the Bonneville area rissoid (represented by *Amnicola porata* and *A. cincinnatiensis*).

(3) That increase in salinity finds a biologic expression (*a*) in depauperation, (*b*) in lessened abundance, and (*c*) in extinction when the waters become briny.

(4) That the oscillations of the lakes are coupled with (*a*) varying abundance, and (*b*) with varying size of shells, as a biologic expression of climate.

## CHAPTER III.

### DESCRIPTIONS OF NEW FORMS.

### VALVATIDÆ.

#### Genus VALVATA Müller.

**Valvata sincera var. utahensis var. nov.**

(Plate VI, Figs. 1–3.)

Testa operculata, anguste umbilicata, conica, striatula, nitida, subpellucida, apice corneo-fulva, infra albida; spira obtuse elevata, apice plana; sutura perimpressa; anfr. 4, regulariter accrescentes, summi uni-carinati, carina in anfr. inferiore evanescente, ultimo anfr. per-rotundato, $\frac{1}{2}$ longitudinis testæ formanante; apertura circularis, postice subangulata; peristoma simplex, ad proximum anfr. callo tenuissimo juncta; intus albida.

*Habitat.*—Lake Utah, Utah.

Long., 4.80$^{mm}$; lat., 3.20$^{mm}$.

Shell operculate, narrowly umbilicate, conical, with minute transverse striæ, shining, somewhat pellucid, yellowish horn color at apex, white below; spire obtusely elevated, flattened at tip; suture well impressed; whorls four, convex, regularly increasing, the uppermost ones with a single well-marked carina, which becomes obsolete on the last whorl; last whorl equals one-half the whole length of the shell; aperture circular slightly angled posteriorly; peristome simple, continuous, joined to the next whorl above by a very slight calcareous deposit; within white.

Operculum light horn color, corneus, spirally multi-volute, slightly produced posteriorly to conform to the shape of the aperture. Dentition unpublished.

Length, 4.80$^{mm}$; breadth, 3.20$^{mm}$.

This form was dredged in August, 1883, in great numbers in Utah Lake, near Lehi, not far from the head of the River Jordan. It is intermediate between *Valvata sincera* Say and *V. virens* Tryon. From the first it differs in the uni-carinate upper whorls, in being more elevated, in possessing a very much smaller umbilicus, and in its greater size.

From the second it differs in color, size, carination, and form of aperture. It resembles, in some respects, *V. unicarinata*, De Kay (=*V. tricarinata* Say), but differs in size, ornamentation, and form of aperture. Specimens may be seen in the Smithsonian Institution, in the New York State Museum of Natural History, and in the private collections of Beecher, Stearns, Dall, Aldrich, and the writer.

## RISSOIDÆ.

### Genus AMNICOLA Gould & Haldeman.

#### Amnicola dalli sp. nov.

(Plate VI, Figs. 4-6.)

Testa anguste umbilicata, obtuse conica, nitida, leviter striata, fusca vel virido-cornea; anfr. 4, convexi, lente accrescentes; sutura regulariter impressa, sub-profunda; apertura ad basim rotundata, postice subangulata, intus cæruleo-albida; peristoma simplex, acutum, marginibus crasso callo junctis; margo columellaris subreflexus.

Long., 3.50$^{mm}$; lat., 2.30$^{mm}$.

*Habitat.*—Mountain streams, Nevada.

Shell narrowly umbilicate, obtusely conical, shining, slightly striated, brown or greenish horn color; whorls four, convex, gradually increasing in size; suture regularly impressed, somewhat deep; aperture rounded before, somewhat angular behind, bluish white within; lip simple, sharp, margins joined by a thick callous, columella rather reflexed.

Length, 3.50$^{mm}$; lat., 2.30$^{mm}$.

For the diagnosis of the lingual dentition I am indebted to Mr. Charles E. Beecher, who has prepared the following description and illustrations:

"Jaw thin, membranaceous.

"Odontophore 1.10$^{mm}$ long, .13$^{mm}$ wide. In a full-grown example the odontophore has 94 transverse rows of teeth, with the formula 3 —1 —3.

"Rhachidian tooth short and broad, with the inferior lateral angles produced. Cusp with seven denticles, of which the central one is the largest. The anterior lateral faces are each furnished with a short strong conical denticle, and the adjacent lateral margin of the tooth is thickened and slightly produced. Formula for rhachidian tooth $=\frac{3+1+3}{1+1}$.

"Body of intermediate tooth quadrate; infero-interior angle somewhat produced; furnished with a large bullation, into which the infero-interior angle of the succeeding tooth appears to fit as if for articulation. Peduncle long and straight. Cusp with seven strong angular denticles, arranged according to the formula 2+1+4.

"Body of the first lateral tooth elongate-triangular, oblique to the

direction of the broad peduncle. Cusp inflected and carrying twenty-three slender denticles.

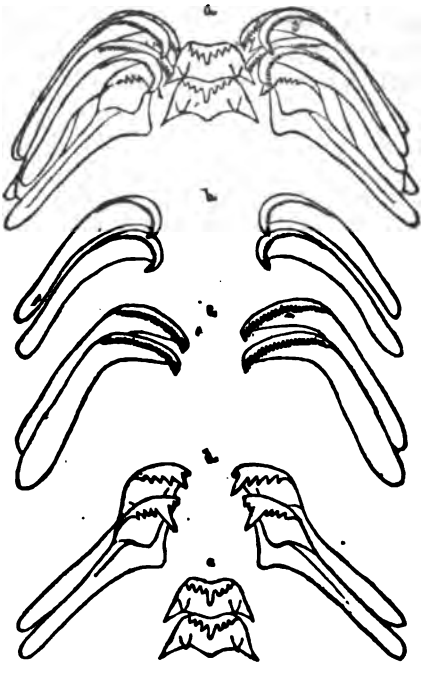

FIG. 2.—Lingual dentition of *Amnicola dalli*, Call × 400.—Beecher.

*a*.—Two of the transverse rows of the odontophore, showing the normal position of the teeth. The teeth are considered as opaque.
*Analysis*. *b*.—Outer laterals. *c*.—First laterals. *d*.—Intermediate teeth. *e*.—Rachidian teeth.

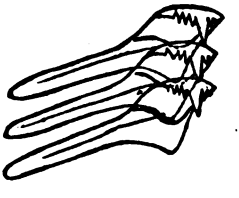

FIG. 3.—Intermediate teeth (×400) showing mode of articulation.—Beecher.

"Outer lateral tooth hamate, with no marked distinction between the body and peduncle. Free extremity incurved and bearing thirty-four minute denticles. The denticle formula is, therefore—

$$34-23-7-\frac{3+1+3}{1+1}-7-23-34.$$

"The apparent articulation of the intermediate teeth, as described above, was observed in a fragment of an odontophore which presented a lateral aspect under the microscope. It is not known that this feature has ever been noted in any other species, although it very proba-

bly occurs in many which have foraminated or bullate teeth. This disposition of the teeth would allow great flexion of the odontophore without their displacement."

This quite distinct form was collected in considerable numbers at Symon's Stage Station, near the foot of Pyramid Lake, Nevada. Its nearest congener is *A. porata* Say, from which it differs in elevation, sculpturing, and dentition. Since this last character is the one of chief importance, the description of the dentition is here given. Comparing the denticle formulæ of the two forms, thus:

*A. porata.*

$$30-18-5-\frac{3+1+3}{4+4}-5-18-30,^{28}$$

*A. dalli.*

$$34-23-7-\frac{3+1+3}{1+1}-7-23-34,$$

the dissimilarity is strongly marked. Specimens may be seen in numerous private collections and in the cabinets of the Smithsonian Institution and the New York State Museum of Natural History.

## LIMNÆIDÆ.

### Genus RADIX Montfort.

**Radix ampla, var. utahensis, var. nov.**

(Plate VI, Figs. 7–9.)

Testa globosa, sub-umbilicata, irregulariter costata, corneo-albida, sub-pellucida; spira parvula, conica; anfr. 4–4½, convexi, supra valde-plani, rapide accrescentes, ultimo inflato, cum transversis costatis perspicatis minutissime corrugatisque; sutura sub-profunda, regulariter impressa; apertura elongato-ovata, effusa, intus margarita-alba; labrum simplex, marginibus callo junctis; columella reflexiuscula, antice recta.

Long. 13.40$^{mm}$; lat. 7.10$^{mm}$.

Aper. long. 9.00$^{mm}$; aper. lat. 5.90$^{mm}$.

Habitat, Lake Utah, Lehi, Utah.

Shell globose, somewhat umbilicated, irregularly costate, light horn color, nearly pellucid; spire rather small, conical; whorls four to four and one-half, convex, somewhat flattened above, giving rather a shouldered appearance to the whorls, rapidly increasing in size, the last whorl being inflated, with numerous rather marked transverse costæ, minutely wrinkled; suture somewhat deep, regularly impressed; aperture elongately ovate, effuse, approaching patulous, pearly white within; outer lip simple, the margin connected by a slight calcareous deposit; columella somewhat twisted, but straight in front. Dentition

[28] After Stimpson, Smithsonian Misc. Coll. No. 201, p. 14, Fig. 6; also *ibid.*, No. 144, p. 80, Fig. 158.

unpublished. Length of largest specimen 16.82mm; breadth 8.88mm. The average of nine specimens gave a length of 13.40mm, breadth 7.10mm, with about the same ratio for corresponding measurements of aperture. Utah Lake, near Lehi, Utah.

This is a rare form in Utah Lake, its only locality so far as known. Its nearest affinity is indicated in the nomenclature adopted. In the preceding chapters its relation to *Polyrhytis kingii* Meek, has been noted. It was associated with abundant specimens of the *Valvata* herein described, and with *Fluminicola fusca* Hald., and *Sphærium dentatum* Hald. Specimens may be seen as above.

## Genus LYMNOPHYSA Fitzinger.

### Limnophysa bonnevillensis, sp. nov.

(Plate VI, Figs 10–13.)

Testa umbilicata, elongata, ventricosa vel bullata, solidula, obsolete striata, minutissime reticulata, in anfr. infra suturam ultimo longitudinaliter obsolete costulato; spira elevata, acuta; sutura perimpressa; anfr. 4–4½, per-convexi, ultimo ¾ longitudinis testæ adæquante et subito accresente, ventricosa, basi subexpanso; columella subplicata, leviter callosa, regulariter arcuata; columella peristomateque continuatis; peristoma simplex, marginibus callo crasso junctis; apertura late-ovalis, ½ totius longitudinis æquans, satis obliqua, postice angulosa.

Species fossilis, Bonneville Lake beds, Utah. Quaternary.

Shell umbilicated, elongate, ventricose or bullate, somewhat solid, faintly striate and very minutely reticulated, below the suture the last whorl bearing faint longitudinal ridges or costæ; spire elevated, acute; suture deeply impressed; whorls 4 to 4½, very much rounded, sometimes tending to geniculation above, the last whorl equal to three-fourths the whole length of the shell, rapidly increasing in size, much swollen, somewhat expanded at base; columella somewhat plicate, slightly callous, regularly arcuate; columella and peristome continuous; peristome simple, margins joined by a heavy callous which is continuous and so reflexed as to partially close the umbilicus; aperture broadly ovate, often patulous, equal to one-half the entire length of the shell, oblique, angled slightly behind.

Fossil, Quaternary. Bonneville Lake beds, Kelton, Utah.

The four largest specimens of the many in the collections give the following dimensions:

| Specimen. | Length. | Breadth. |
|---|---|---|
| | mm. | mm. |
| 1 | 15.00 | 7.80 |
| 2 | 11.00 | 5.80 |
| 3 | 9.40 | 5.20 |
| 4 | 18.50 | 6.00 |

This shell resembles depauperate examples of *L. sumassi*, Baird (var. *P. palustris* Müller), but differs in not presenting a decussate surface, and in the columella being less strongly plicate. The greater number of specimens are somewhat malleated, though occasionally quite smooth specimens occur which approach nearest to *L. desidiosa* Say. Many present a patulous aperture, in which respect they resemble specimens of the genus *Radix* rather than true *Limnophysa*. The general outline of the specimens is that of *L. adelinæ* Tryon. Collected abundantly by Mr. G. K. Gilbert, in Upper Bonneville beds, at Kelton, Utah.

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## PLATE II.

Each conventional sign represents a shell, and its position represents the dimensions of the shell. The lengths are found by reading from below upwards; the breadths by reading from left to right. The marginal numbers represent millimeters.

The average of the given series is represented by the closed conventional sign.

DIAGRAM 1.

Based upon Table VI, page 31. *Pompholyx effusa* Lea.

The circles represent specimens from Pyramid Lake, Nevada; the squares specimens from White Pine, Nevada.

DIAGRAM 2.

Based upon Table VII, page 32. *Pompholyx effusa* Lea.

The circles represent fossil shells from the gray tufa, Anaho Island, Pyramid Lake, Nevada; the squares fossil shells from the marl at White Terrace; and the triangles represent living shells from Pyramid Lake, Nevada.

*DIAGRAM I.*

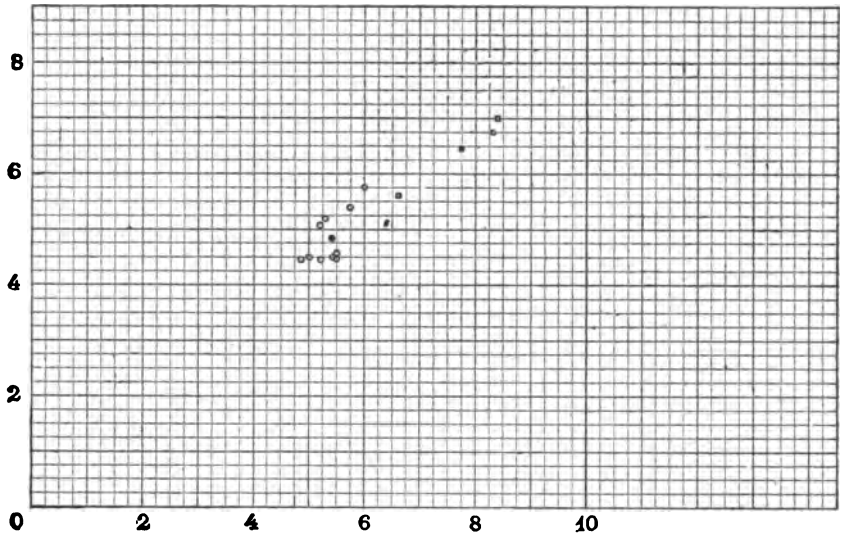
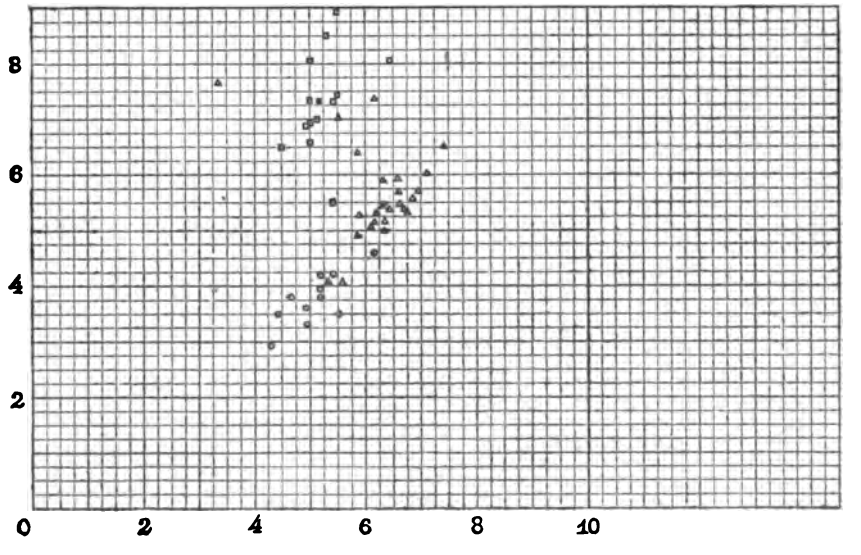



*DIAGRAM II.*




COMPARATIVE DIMENSIONS OF POMPHOLYX EFFUSA

## PLATE III.

Each conventional sign represents a shell. The lengths are found by reading from below upwards; the breadths, by reading from left to right. The marginal numbers represent millimeters.

The average of the given series is represented by the closed conventional sign.

DIAGRAM 1.

Based upon Table VIII, page 32. *Carinifex newberryi* Lea.

The circles indicate fossil specimens from the south end of Winnemucca Lake, Nevada; the squares represent semi-fossil shells from Christmas Lakes, Oregon.

DIAGRAM 2.

Based upon Table IX, page 33. *Helisoma trivolvis* Say.

The circles indicate shells from Warm Spring Lake, Utah; the squares, semi-fossils from Carson Desert, Nevada.

*DIAGRAM I.*

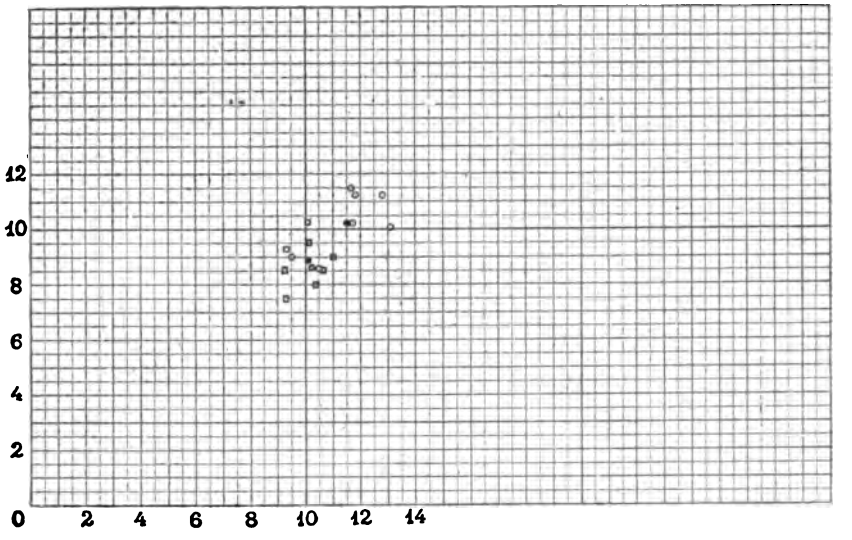
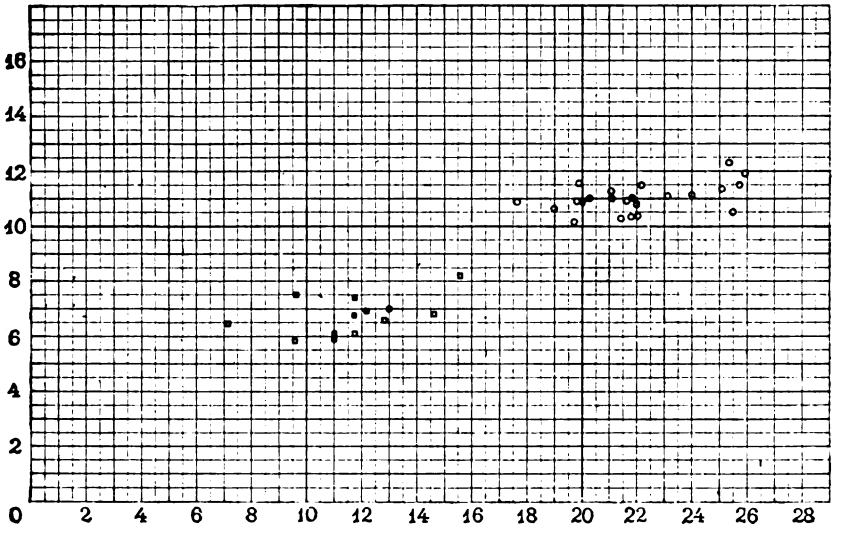



*DIAGRAM II.*




COMPARATIVE DIMENSIONS OF SHELLS

## PLATE IV.

Each conventional sign represents a shell. The lengths are found by reading from below upwards; the breadths, by reading from left to right. The marginal numbers represent millimeters.

The average of the given series is represented by the closed conventional sign.

DIAGRAM 1.

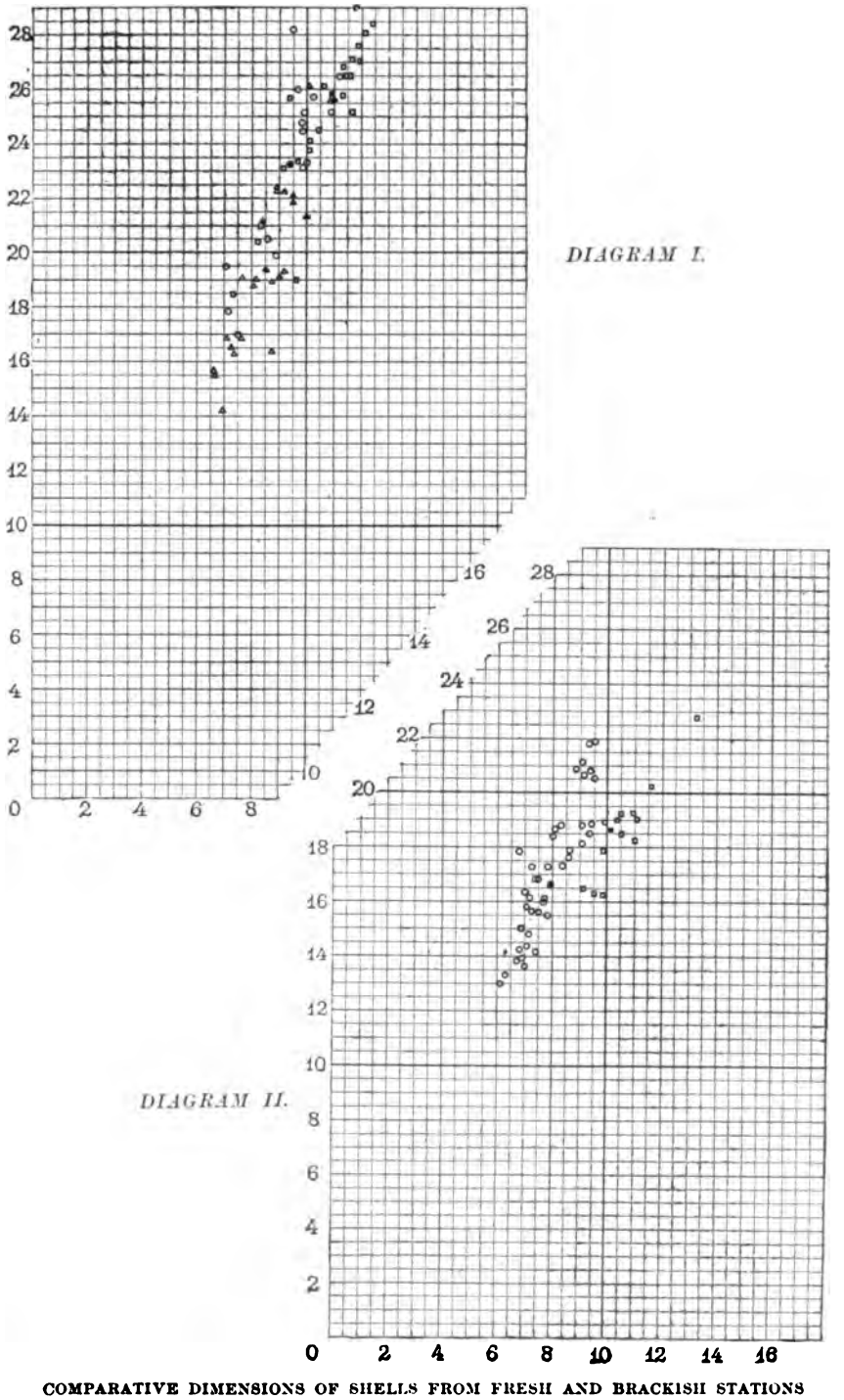
Based upon Table X, page 34. *Limnophysa palustris* Müll.

The circles represent specimens from Honey Lake, California; the squares, shells from Warm Spring Lake, Utah; and the triangles, specimens from brackish springs, Promontory, Utah.

DIAGRAM 2.

Based upon Table XI, pages 34 and 35. *Physa gyrina* Say.

The circles represent shells from brackish springs, Promontory, Utah; the squares, specimens from fresh-water ponds at Salt Lake City, Utah.




COMPARATIVE DIMENSIONS OF SHELLS FROM FRESH AND BRACKISH STATIONS

## PLATE V.

Each conventional sign represents a shell. The lengths are found by reading from below upwards; the breadths, by reading from left to right. The marginal numbers represent millimeters.

The average of the given series is represented by the closed conventional sign.

DIAGRAM 1.

Based upon Table XIV, page 39. *Physa ampullacea* Gould.

The circles represent shells from Little Gull Lake, California; the squares represent shells from Church Lake, near Salt Lake City, Utah.

DIAGRAM 2.

Based upon Table XVI, page 41. *Fluminicola fusca* Hald.

The circles represent fossils from Kelton, Utah; the squares, shells from Ogden River; and the triangles, specimens from Utah Lake, Utah.

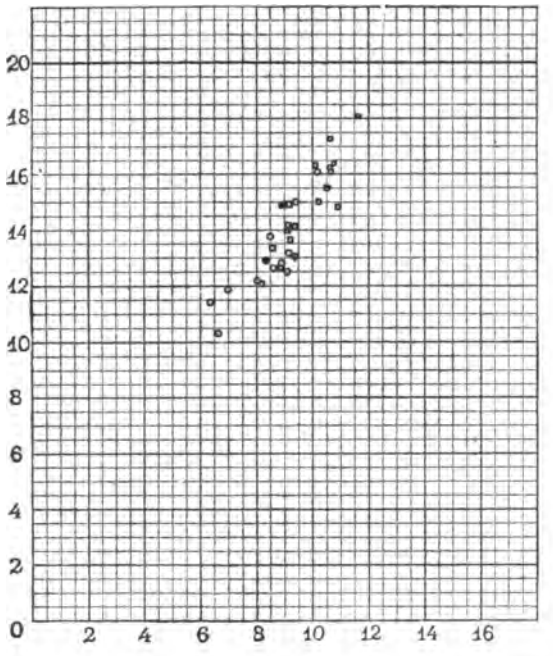



DIAGRAM I.

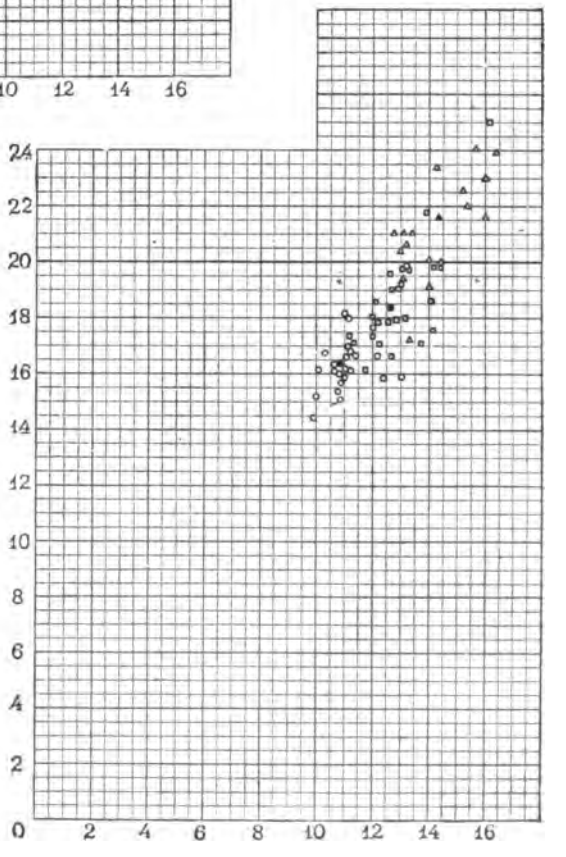



DIAGRAM II.

COMPARATIVE DIMENSIONS OF SHELLS

## PLATE VI.

Page.

*Valvata sincera*, var. *utahensis* ..... 44

Fig. 1. Front.
Fig. 2. Top.
Fig. 3. Back.

*Amnicola dalli* ..... 45

Fig. 4. Front.
Fig. 5. Top.
Fig. 6. Back.

*Radix ampla*, var. *utahensis* ..... 47

Fig. 7. Front.
Fig. 8. Top.
Fig. 9. Back.

*Limnophysa bonnevillensis* ..... 48

Fig. 10. Front.
Fig. 11. Top.
Fig. 12. Back.
Fig. 13. Smooth individual; front.

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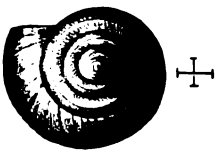

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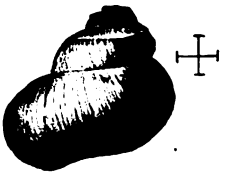

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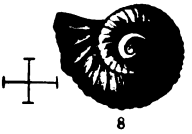

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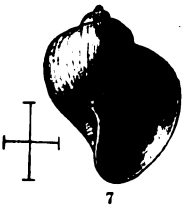

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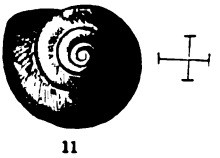

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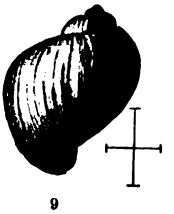

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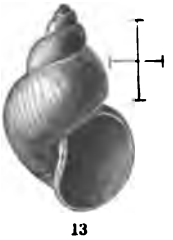

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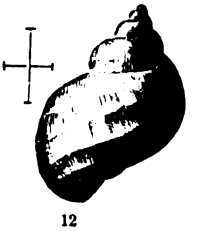

12

RECENT AND QUATERNARY MOLLUSCA.

# ADVERTISEMENT.

(Bulletin No. 12.)

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The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classifications of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary o the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization. And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated; the "usual number" (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document-rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments, and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the second, third, fourth and fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Williams's Mineral Resources, the Survey has no copies of any of its publications for gratuitous distribution.

## ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. lv, 568 pp. 61 pl., 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

## MONOGRAPHS.

So far as already determined upon, the list of the Monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. Published.

IV. Comstock Mining and Miners, by Eliot Lord. Published.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. Published.

VI. Older Mesozoic Flora of Virginia, by Prof. William M. Fontaine. Published.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. Published.

VIII. Paleontology of the Eureka District, Nevada, by Charles D. Walcott. In press.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by R. P. Whitfield. In press.

# ADVERTISEMENT.

Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. In preparation.

Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague. In preparation.

Lake Bonneville, by G. K. Gilbert. In preparation.

Dinocerata: A Monograph on an Extinct Order of Ungulates, by Prof. O. C. Marsh. In preparation.

Sauropoda, by Prof. O. C. Marsh. In preparation.

Stegosauria, by Prof. O. C. Marsh. In preparation.

Of these Monographs, Nos. II, III, IV, V, VI, and VII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by C. E. Dutton, Capt. U. S. A. 1882. 4°. 264 pp. 42 pl. and atlas of 26 double sheets folio. Price, $10.12.

III. Geology of the Comstock Lode and Washoe District, with atlas, by G. F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price, $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price, $1.50.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. 1883. 4°. xvi, 464 pp. 29 pl. Price, $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by William M. Fontaine. 1883. 4°. xix, 128 pp. 54 ll., 54 pl. Price, $1.05.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xii, 200 pp. 15 pl. Price, $1.20.

Nos. VIII and IX are in press and will soon appear. The others, to which numbers are not assigned, are in preparation.

## BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper, and be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price, 10 cents.

2. Gold and Silver Conversion Tables, giving the Coining Value of Troy Ounces of Fine Metal, &c., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price, 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the Meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price, 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price, 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price, 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price, 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price, 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. Price 10 cents.

9. A Report of the Work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8° 74 pp. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. Price, 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 24 pp. Price, 5 cents.

## STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, is contemplated. Of that series the first has been published, viz: Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price, 50 cents.

Correspondence relating to the publications of the Survey, and all remittances, which must be by postal note or money-order, should be addressed to the

DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY,
*Washington, D. C.*

WASHINGTON, D. C., *September* 30, 1884.

DEPARTMENT OF THE INTERIOR

# BULLETIN

OF THE

# UNITED STATES

# GEOLOGICAL SURVEY

## No. 12

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

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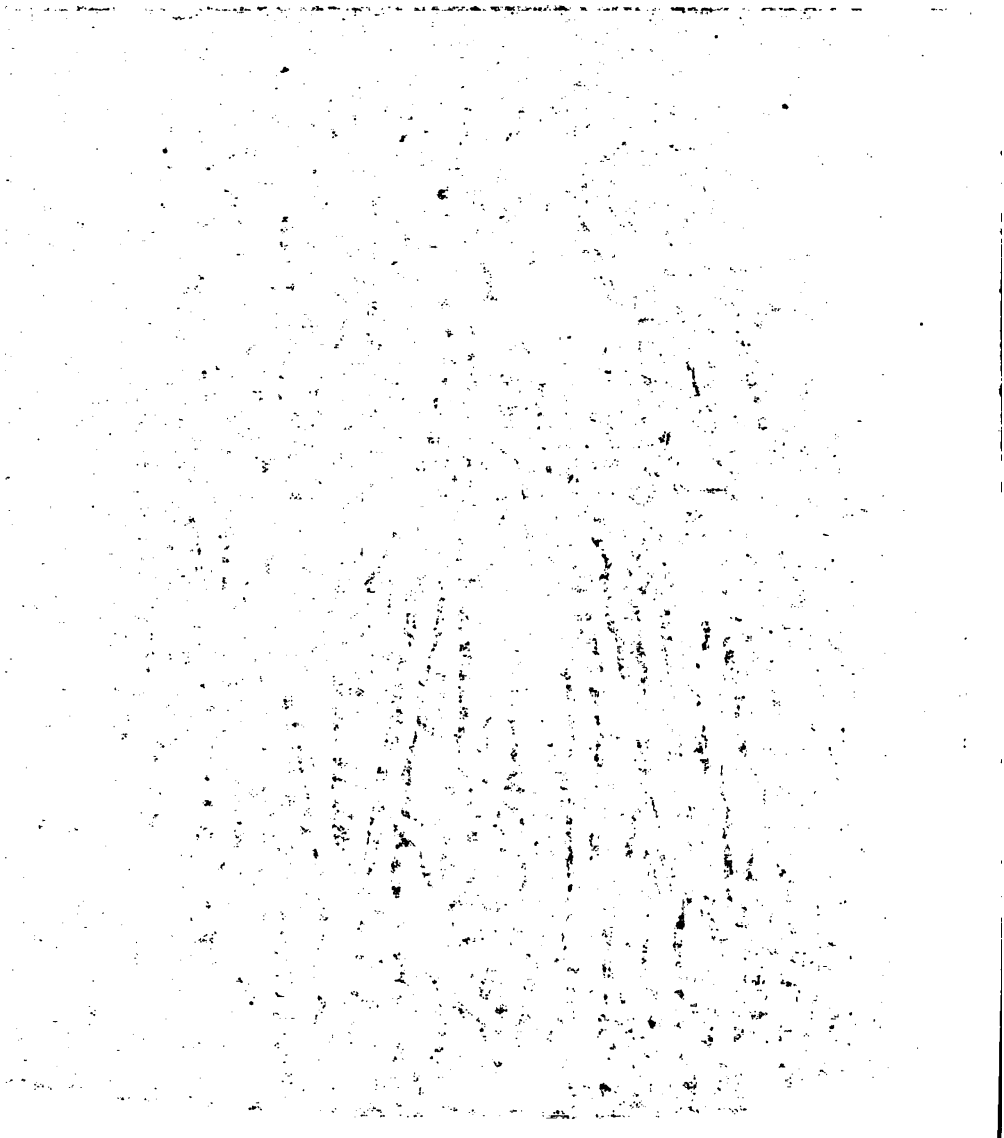

UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL DIRECTOR

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A

# CRYSTALLOGRAPHIC STUDY

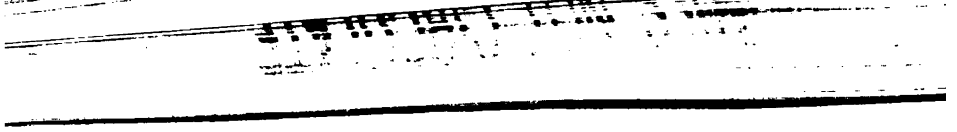
OF THE

# THINOLITE OF LAKE LAHONTAN

BY

EDWARD S. DANA

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884



## LETTER OF TRANSMITTAL.

---

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE GREAT BASIN,
*Washington, D. C., September* 16, 1884.

SIR: I have the honor to transmit herewith, for publication, a paper on Thinolite, by Prof. Edward S. Dana, of New Haven.

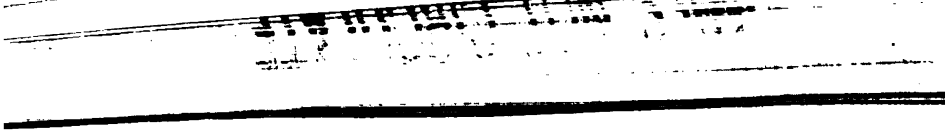
The calcareous pseudomorph to which Mr. Clarence King gave the name "thinolite" has been referred by him and others to the mineral gaylussite, and the history of its conversion to calcite was believed to afford the key to the history of the oscillations of Lake Lahontan. Mr. Russell's later and fuller investigations demonstrated the physical impossibility of the lake-history deduced by King, and the question of the origin of the thinolite was thus reopened. Mr. Russell determined its distribution and geologic relations in a thorough and satisfactory manner, but his acquaintance with mineralogy did not permit him to undertake the necessary crystallographic study with confidence.

Application was accordingly made to Profs. George J. Brush and E. S. Dana, and the study of the mineral was finally undertaken by the latter gentleman. His report, which is eminently judicial and conservative, does not contain a complete solution of the problem; but it clears the ground by dissipating all earlier hypotheses, and indicates the line of future investigation. It renders to the geologic study the important service of freeing it from the embarrassment occasioned by the gaylussite hypothesis.

I remain, with great respect, your obedient servant,

G. K. GILBERT,
*Geologist in Charge.*

Hon. J. W. POWELL,
*Director United States Geological Survey.*



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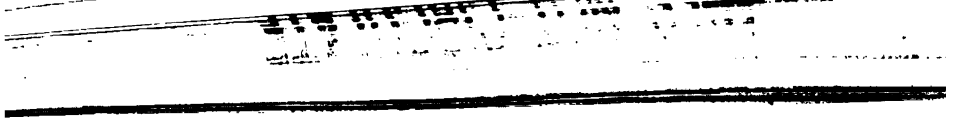

# A CRYSTALLOGRAPHIC STUDY OF THE THINOLITE OF LAKE LAHONTAN.

By Edward S. Dana.

## INTRODUCTORY STATEMENT.

*Origin of the name Thinolite.*—The name Lake Lahontan was given by Mr. Clarence King to the great Quaternary lake of northwestern Nevada, of which the present Walker, Carson, Humboldt, Winnemucca, Pyramid and Honey lakes are the relics. The extent of Lake Lahontan was first mapped out by Mr. King, and a description of it and of its history is given in his report.[1] As shown by him, the characteristic feature of the Lahontan Basin is the great abundance in it of deposits of calcareous tufa. Of this he says:[2]

"As compared with Lake Bonneville, the chief characteristic difference in the phenomena of terraces and shore lines is the great abundance in the Lahontan Basin of calcareous tufas. Modern subaerial gravels have been in great measure washed down over the calcareous matter, but it frequently exists even in the broad bottom of the lake in thick accumulations—covering areas of several miles with a tufaceous deposit from 20 to 60 feet thick. As will be seen later, this tufa is of very great chemical interest, and its mineralogical nature affords a clew to the history of the lake. From its very great importance and its peculiar origin, I have taken the liberty of giving it a lithological name. Since it formed on the shores of the lake, I have called it, from the Greek Θίς (shore), Thinolite."

The occurrence and characters of this tufa are described in considerable detail by Mr. King, and its general appearance is well shown in several plates in his report. Mr. King also discusses the condition of the formation of the calcareous tufa, and offers an explanation of its origin, to which reference will be made later.

[1] Clarence King: Report of the Geological Exploration of the Fortieth Parallel, Vol. I, p. 488, *et seq.*, 1878.

[2] *Loc. cit.*, p. 508.

## VARIETIES OF TUFA.

The Lahontan Basin has recently been studied by Mr. I. C. Russell, and a preliminary sketch of its geological history was published in 1883, embodying the results of a reconnaissance in the season of 1881.[3] A complete report, embracing the results of later observations, is now in preparation.

Mr. Russell has mapped with great completeness the geographic extent of Lake Lahontan, and has traced out the topography of its shores at the different stages in its history. With respect to the calcareous deposits, he has been led to discriminate between three distinct varieties, superimposed upon each other, to which he gives the names *lithoid*, *thinolitic*, and *dendritic*. The following points with regard to them are taken nearly *verbatim* from his report.

The *lithoid tufa* was the first formed tufa deposit; it is found on the slopes of the basin from the level of the lithoid terrace, which is 30 feet below the highest water line of Lake Lahontan, downward as far as any sections are now exposed. This variety of tufa is usually gray in color and compact in structure; it occasionally shows concentric bands and open spaces, but is much more dense and stone-like than the varieties deposited later.

The *thinolitic tufa* forms the second layer, and was deposited at a lower stage of the water. Its upper limit on the sides of the basin is the thinolite terrace, which is 400 feet lower than the lithoid terrace just alluded to, and 100 feet above the present level (1881) of Pyramid Lake. A minor deposit probably also occurred (as noted in a subsequent paragraph) after the formation of the dendritic tufa. This second variety of tufa, to which the name *thinolite* is now restricted, is characterized by the fact that it consists of groups of distinct prismatic or pyramidal crystals, as will be described later. In the Lahontan Basin the thinolite is best developed about the base of the Marble Buttes, at the south end of Pyramid Lake; at the Needles, at the northern end; and at the Domes, and around the lower portions of Anaho and Pyramid islands, in the same lake. It occurs all along the borders of Winnemucca Lake, and less abundantly on Smoke Creek and Black Rock deserts. These deserts form a single basin, separated from the valley of Pyramid Lake by a low divide. It is found also along the borders of Carson Desert, and at a single locality in Walker Lake Valley. Outside of the Lahontan Basin it occurs in the basin of Mono Lake, in California. The deposits of thinolite are of very considerable magnitude; where best exposed the layer of interlaced crystals has a thickness of from 6 to 8 feet, and exhibits concentric zones of larger and smaller crystals.

[3] I. C. Russell: Sketch of the Geological History of Lake Lahontan, a Quaternary lake of northwestern Nevada. Washington, 1883. (Department of the Interior, U. S. Geological Survey, J. W. Powell Director.)

The *dendritic tufa* is the third variety of calcareous deposit in the Lahontan Basin. Its upper limit is about 200 feet below the highest water line, and from this level it coats the sides of the basin wherever the conditions were favorable. It is by far the most abundant of the three kinds of tufa, and in places attains a great thickness. Its greatest depth is not less than 20 feet, and may be as much as 50 feet. This kind of tufa is characterized by its distinct dendritic structure. It occurs over large portions of the bottom of the old lake, forming mushroom-shaped masses of all sizes up to 5 or 6 feet in diameter; in some places they make a pavement of blocks 2 feet in diameter, resting on the lake beds.

## SUCCESSION OF TUFA DEPOSITS.

As has already been intimated, Mr. Russell has found that the three varieties of tufa succeeded each other in the order named above. Later observations have shown, as he has informed the writer, the probable existence of a second deposit of thinolite crystals, not exceeding 4 or 5 inches in thickness, which followed the precipitation of the dendritic tufa. The succession of the three prominent deposits of tufa in their relation to each other and the sides of the basin is illustrated by Mr. Russell by the accompanying figure. With his permission I insert this figure, and also quote two or three pages from his preliminary report descriptive of the succession of tufa deposits, their chemical composition, and general method of occurrence (pp. 215 to 218):

"The accompanying diagram, Fig. 48 [Fig. 1 of this publication], gives a generalized expression of the relation of the three successive

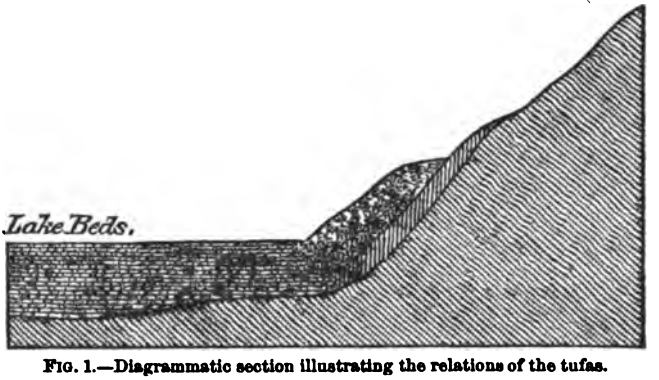


FIG. 1.—Diagrammatic section illustrating the relations of the tufas.

tufas to each other and to the sides of the basin. The first formed deposit, the lithoid tufa, represented in the notation of the diagram by vertical lines, extends upward about 500 feet above the horizontal lake beds occupying the bottom of the basin. The second deposit, the thinolitic tufa, finds its upper limit 100 feet above the present level of Pyramid Lake. The third and last, the dendritic tufa, which is far

more abundant than either of the others, extends upward to within about 200 feet of the highest shore line. The lower limits of these deposits cannot be determined with certainty, as they are concealed by lake beds.

"Chemical analyses were made by Prof. O. D. Allen of samples of each of these varieties of tufa, and the results, given below, show that their constituents are practically identical. The insoluble residue exhibited in each case may be due in part to foreign matter imprisoned in the tufa at the time of its formation, and is certainly due in a measure to foreign matter carried by atmospheric agencies into open cavities of the rock after the desiccation of the lake.

| Constituents. | Lithoid tufa. | Thinolitic tufa. | Dendritic tufa. |
|---|---|---|---|
| Insoluble residue | 1.70 | 3.88 | 5.06 |
| Lime (CaO) | 50.48 | 50.45 | 49.14 |
| Magnesia (MgO) | 2.88 | 1.37 | 1.99 |
| Oxides of iron and alumina | .25 | .71 | 1.29 |
| Carbonic acid ($CO_2$) | 41.85 | 40.90 | 40.31 |
| Water ($H_2O$) | 2.07 | 1.50 | 2.01 |
| Phosphoric acid ($P_2O_5$) | .30 | Trace. | Trace. |
| Chlorine and sulphuric acid | Trace. | Trace. | Trace. |
| | 99.53 | 98.81 | 99.80 |

"Not only do these tufa deposits still sheathe the slopes of the Lahontan Basin, but they appear also in isolated, castellated masses and rugged crags about the shores of Pyramid and Winnemucca Lakes and on the borders of the Carson Desert. These outstanding masses occur characteristically as upright cylinders, or groups of cylinders, with rounded, dome-shaped tops, and are of all sizes, from a few inches up to a hundred feet or more in height. The larger masses are composed of groups of many tower-like, cylindric bodies of unequal height, and bear a striking resemblance to rugged mediæval castles with rounded towers and castellated battlements. A fine example of such a water-built castle stands about the middle of the western shore of Pyramid Lake, and rises 100 feet above the waves that wash its base. The domes between the eastern shore of the lake and Pyramid Island are the tops of similar towers, the foundations of which are deeply submerged. Other masses of the same nature, but smaller in size and usually broken and weathered, occur in abundance. Frequently these outstanding cylinders and castles of tufa are broken across, or split from base to summit, so as to reveal every desired section of their interiors. An examination of a large number of these dissected masses brought to light the interesting fact that all the tufa crags below the broad terrace 100 feet above Pyramid Lake—the thinolite terrace—have a tripartite structure, and all above that horizon have a bipartite structure.

"Each of the tufa towers below the thinolite terrace has a core of compact gray tufa in all respects identical with the first-formed sheath of tufa on the rocky sides of the basin. This core of lithoid tufa is com-

monly from 2 to 6 feet in diameter, and sometimes shows a tubular structure. When the base is exposed it is occasionally seen to spring from a small nucleus of rock.

"Outside the core of gray tufa is a coating of thinolite crystals, from 2 to 6 or 8 feet thick, that completely envelops its sides and top. These crystals are interlaced in every direction, but show a radial grouping, and also a concentric banded structure—zones of elongated prisms alternating with narrow bands of smaller crystals. The largest crystals are from 6 to 10 inches in length and an inch or more in diameter. This layer of thinolite is best displayed in the masses of tufa that occur low down near the surface of Pyramid Lake. The deposit is there thickest and the crystals are largest.

"About the layer of thinolite, and in turn completely covering it, is a third tufa deposit, equal to or even exceeding in thickness either of the previous layers. It usually arches over the top of the column in a low dome. This third layer is of dendritic tufa, and always shows the characteristic branching structure, resembling a group of cedar boughs changed to stone.

"Frequently the dome-shaped summits of these tufa towers are weathered into holes, and sometimes the entire top is dissolved away down to the layer of thinolite crystals, or even deeper. In the hollows thus formed, which are frequently 10 or 12 feet in diameter, a person can stand as on the top of a wide tower, with a parapet of dendritic tufa 3 or 4 feet high all about him. On the west side of Winnemucca Lake, near the southern end, there stands a tufa tower, fully 40 feet high, that has been split from base to summit into three sections, the open fractures being wide enough for a person to pass through. In remembrance of Heidelberg, I have called this the 'Rent Tower.' The whole of this tower is composed of tufa, the nucleus from which it started being some distance below the surface of the surrounding lake beds and gravels. It stands just above the level of the thinolite terrace, and is composed entirely of lithoid and dendritic tufa, the middle or thinolitic member being wanting. Near at hand, and a few feet below the horizon of the thinolite terrace, are other dome-shaped masses, showing the intermediate thinolite also.

"While the isolated tufa towers having thinolite as a middle member are confined to the shores of Pyramid and Winnemucca Lakes and to the borders of the Carson Desert, the similar masses in which the thinolite is wanting occur over a much wider area, especially along the borders of the Black Rock Desert. Examples may also be seen along the line of the Central Pacific Railroad southeast of Humboldt Lake.

"In some cases, where the lake beds and gravel have been washed away from the base of a tufa tower, we find the outer layer of dendritic tufa projecting as an irregular shoulder about the lower part of the column, thus showing how much of the column projected above the bottom of the lake at the time the dendritic layer was added. In one instance,

where the entire mass has been uprooted, the layer of thinolitic crystals extends about 2 feet lower down than the coating of dendritic tufa, and then terminates in the same abrupt manner. In this case the central core of lithoid tufa ends in a tapering, irregular base, the nucleus of which is a group of small pebbles.

"One of the physical conditions favorable, if not absolutely necessary, for the formation of tufa seems to be the presence of a solid nucleus about which the carbonate of lime can commence to crystallize. This nucleus may be a pebble resting at the bottom of the lake or it may be the solid cliff that forms the shore. It plays the same rôle here as it does in the crystallization of alum or rock candy in a laboratory experiment, or as may be seen in the structure of oolitic sand. The crystallization once started, the process was continued until hundreds and even thousands of tons had formed in a single isolated mass. Where the shores are too steep and solid for the ready formation of terraces and embankments of gravel, they favor the deposition of tufa. In such places the chemical deposit cannot be disturbed or carried away by the shore drift. The most favorable places of all for the accumulation of calcareous deposits are rocky islands. Tufa frequently cements the gravel and sand of which embankments are constructed, and sometimes forms a complete pavement on their surfaces. This happens when by a rise of the lake the surface of the embankment is so far submerged as to escape the action of the shore drift. Tufa has never been observed by the writer resting on beds of fine clay or silt unless there were pebbles for nuclei. In many instances every pebble on a surface of fine lake beds has its upper surface coated with tufa, or perhaps supports a mushroom-shaped growth some inches in height, while the surrounding plain of fine mud is entirely free from calcareous deposit."

## CRYSTALLOGRAPHIC STUDY.

The introductory statements which have been made will have served to give a sufficiently clear idea of the general relations of the calcareous tufas of the Lahontan basin, as established by the labors of Mr. Russell. The immediate object of the present writer is to state the results of a mineralogical study of the specimens of thinolite which have been placed in his hands, undertaken with the view to making out as fully as possible the crystalline form, so as to throw light upon the probable chemical nature of the original mineral, and thus further upon the history of the complex changes through which Lake Lahontan has passed.

In order to avoid all misapprehension, it may be repeated here that the word *thinolite* is employed in the restricted sense used by Mr. Russell, as designating that portion of the calcareous tufas which is distinctively crystalline, in distinction from the stony (lithoid) and

dendritic varieties. In a word, the thinolite is a crystalline deposit, now consisting chemically of almost pure calcium carbonate, but obviously pseudomorphous after some original mineral deposited on an immense scale during a certain period in the desiccation of Lake Lahontan.

## GENERAL ASPECT OF THE THINOLITE.

In general it may be said that the thinolite collected from the different localities named, both in the basin of Lake Lahontan and of Mono Lake, while varying widely in external aspect, is yet remarkably uniform in all essential characters. It is thus established beyond question that the original mineral deposited was throughout the same, although, in consequence of the varied conditions to which it has been subjected, the forms resulting from its alteration are very diverse. Thus, in some specimens there is only a delicate skeleton remaining, the whole consisting of thin plates, held together in their parallel position by a slight central frame-work, while in others the whole is as firm and compact as a crystalline limestone, and between the two extremes many intermediate varieties occur. The most important condition upon which this difference depends is the varying extent to which a deposition of calcium carbonate has taken place subsequent to the first alteration of the original mineral. This will be more fully explained later.

## THINOLITE FROM PYRAMID LAKE.

As has already been stated, the thinolite is most characteristically developed about Pyramid Lake. The writer has had in hand specimens from the Marble Buttes, from the Needles, from Anaho Island, and from the Domes, and, as they illustrate well the different varieties, it will be convenient to refer to them by localities, although no special significance is probably to be attached to the particular spot from which the individual specimens were collected.

The delicate, open, porous variety of thinolite is best shown in the specimens from the Marble Buttes, of which illustrations are given in Plate I (here inserted from Mr. Russell's report) and in Fig. 1 (reduced one-half) of Plate II. The external form of the crystals is roughly that of a rectangular prism, with projecting edges and generally tapering toward the extremities. The color is gray to brown. These crystals are commonly from a quarter of an inch to an inch in diameter and up to 8 or 10 inches or more in length. They are generally grouped in a more or less closely parallel position, often compactly, with only very little interlacing. In other cases, especially when the forms are smaller, they have widely divergent positions, interpenetrating each other, and giving a large mass an open, reticulated appearance. In addition to the elongated crystals, numerous smaller ones, half an inch or an inch

in length, make up parts of these masses, projecting from the sides of the larger crystals and forming divergent groups among themselves. The small crystals have generally the form of an acute pyramid, and are sometimes square in outline, sometimes rhombic; the sides are usually concave, and the edges project sharply. The exterior surface of the larger crystals is rough and open, often with a delicate mossy covering, and the whole crystal is porous throughout, as if eaten out so as to leave only a skeleton behind. Upon a superficial examination no regularity in the structure is evident, but on looking more closely it is seen that the apparently rough and irregular surface is made up of portions of thin plates, each set parallel to the sides of the crystal and uniformly converging in one direction. Thus when one of the groups of nearly parallel crystals is viewed end on, from one extremity or the other, it is seen that the edges of the plates, irregular as they are in outline, are all presented to view at once, as if each crystal, though prismatic in general outline, were made up of a series of acute skeleton pyramids, hopper-like in form, placed one within another. Still further, when the section produced by the cross-fracture of one of these elongated crystals is examined, there is seen, more or less distinctly, a series of apparently rectangular ribs forming concentric squares or rectangles, with diagonal ribs joining the opposite angles.

The specimens in hand from the Needles, Pyramid Lake, correspond closely with those which have been described, though hardly showing the structure so clearly. This is also true of some of those from Anaho Island. The majority from the latter locality, however, are much more firm and compact. Here, too, the crystals are usually elongated, and in a single specimen grouped in nearly parallel position. The edges of the plates are also commonly distinct on the sides, and show the same convergence toward one extremity. The masses, however, instead of being open and porous, and consequently light in the hand, are close, compact, and heavy. Instead of the delicate, open skeleton, with fretted surface, seen on the cross-fracture, the section is nearly solid, and sparkles with the reflection from the cleavage surfaces of the calcite grains. In other cases the outer surfaces are smooth and rounded, and the unaided eye sees little of the structure except on a cross-fracture; in these instances, as will be more fully explained immediately, a deposition of calcium carbonate has filled up the skeleton form and incrusted and smoothed over the surface.

The specimens from the Domes represent still another type of the thinolite. The crystals here have uniformly an acute pyramidal form, and are grouped in irregular, divergent positions. Their surfaces are brownish yellow in color and show little of the edges of the parallel plates conspicuous in the variety from the Marble Buttes. They are, on the contrary, nearly smooth, except when covered with warty excrescences, which in some cases are thickly clustered about the edges and extremities. One of these crystals (natural size) is shown in Fig. 11 of

Plate II. On the fracture this variety is found to be nearly as firm and compact as a fine-grained cystalline limestone; in fact, the unaided eye would regard the whole as crystalline throughout. The color on the fracture is slightly yellowish white.

## EXAMINATION OF SECTIONS OF CRYSTALS.

In order to get at the true structure of the crystals which have been described it is necessary to resort to sections cut transversely and longitudinally; these reveal the form most clearly and satisfactorily. A cross-section of a crystal like those first described—the open porous variety from the Marble Buttes—is shown in Fig. 2 (natural size). As seen in the figure it is made up of lines in positions parallel to the sides of a square prism, and in addition there are two sets of distinct diagonal lines intersecting at right angles to each other; between these ribs are open spaces. A closer examination of the specimen represented in Fig. 2 shows that the material consists of rhombohedral calcium carbonate, or calcite, of a distinctly granular crystalline structure throughout. The whole presents an open tesellated appearance. The external form of the crystal which yielded Fig. 2 is shown, reduced one-half, in Fig. 6. The point at which it was divided is indicated by a black line. The form is roughly that of a square prism tapering slightly in both directions, but the external form does not conform, in this respect, to the internal structure except at the upper extremity. The irregular edges of the upwardly converging plates are clearly shown in this figure.

A longitudinal section of another crystal (one-half natural size) is shown in Fig. 5. It presents also an open skeleton appearance analogous to that of Fig. 2. As seen in the figure the plates converge upwards on either side of the longitudinal axis, meeting at an angle of approximately 35°. Like the previous case, it consists entirely of purely granular crystallized calcite with only a little mossy covering on the surfaces of the plates. It is to be noticed here that the plates all converge upwards from one extremity of the crystal to the other, and this, as will be remarked later, is almost universally true even in the case of crystals, the external form of which tapers off at both ends.

Another transverse section (natural size) is shown in Fig. 3. It is like Fig. 2 in most respects, except that the square is elongated in one direction and the diagonals meet in a central rib. Moreover, while the skeleton frame-work consists as before of crystallized calcite (left white in the drawing), the intermediate spaces are partially filled up with a secondary deposit of calcium carbonate which is apparently amorphous, and has been deposited in granular form and, too, in lines parallel to the crystalline plates. This subsequent deposition, however, has not gone far, and the general appearance is nearly as open as the one first described. The outline of the crystal which yielded this section is shown in Fig. 7 (reduced one-half). As seen here it tapers gradually

to the terminal edge, forming a sharp extremity. The external form approximates to the true crystalline form of the original crystal, but is somewhat more acute, as shown by the edges of the plates exposed on the surfaces and by the angle at which the plates within converge.

In Fig. 13 another section is given (natural size). This shows much the same tessellated appearance, the structure being essentially the same as in the others described, but the secondary deposition of amorphous calcium carbonate has gone still further, so that as a whole it is more compact. The skeleton ribs parallel to the sides and the diagonals are, however, still very distinct and entirely crystalline. The form of the crystal which gave this section is shown in Fig. 8 (one-half natural size). As seen here it is an acute square pyramid, approximately conforming in outward form to the internal structure. The surface is here no longer open and fretted, as in the others, but nearly smooth, except as it is covered with small wart-like prominences. The color is a dark brown. The line in which the section was cut is shown in the figure.

Still another section is shown in Fig. 14 (natural size), and one which marks a further degree of deposition of secondary calcium carbonate. The crystal from which it was taken had a square form tapering slowly upward, and the surface was covered with small mammillary prominences. The skeleton of crystalline calcium carbonate is here nearly concealed by the added amorphous material, and the outer portion consists of concentric layers of the same substance.

The exterior appearance of another crystal is shown in Fig. 4 (one-half of natural size). As seen, it tapers slightly toward both extremities, and it was cut longitudinally, in the idea that it might be a doubly terminated crystal, but the structure lines all converged toward one end, showing that, like most of the others, the growth was only in one direction. As the surface indicates, the crystalline skeleton has been nearly filled up with amorphous calcium carbonate.

In addition to the sections given and others like them of large crystals, numerous thin sections were also cut transverse and longitudinal to smaller crystals. They revealed under the microscope the same points which the microscopic examination of the larger sections showed—that is, the presence of the same skeleton of crystallized calcium carbonate with the concretionary depositions added to it. The calcite grains are large, each one having a distinct rounded or elliptical outline, and they are packed closely together, with a little brownish amorphous matter between them. Many of them show the rhombohedral cleavage; others show a crystalline nucleus which has apparently grown by the addition of further crystalline matter. The secondary calcium carbonate has generally a concentric or banded structure resembling some kinds of opal.

These sections also show another point of interest, namely, the presence of groups of acicular crystals in parallel position filling more or

less completely the cavities in the skeleton structure, and sometimes projecting into the cavities. These are seen in many cases, and are the general rule, though sometimes absent; they are indicated magnified eight times in Fig. 15. These acicular crystals show uniformly extinction parallel to their prismatic direction, and hence it seems clear that they must belong to an orthometric system. It seems probable that they are aragonite. A chemical examination of an uncovered slide gave results in accordance with this suggestion.

A section of one of the crystals from the Domes is shown in Fig. 12 magnified eight times. To the eye the broken crystal appeared to be crystalline throughout; in the section, however, as examined under the microscope there is seen to be a crystalline frame-work made up of calcite grains, filled in with amorphous matter, and in addition outer layers of banded opal-like carbonate, so that it conforms in general to cases like those before represented. The diagonal lines are here clearly developed, and there are also rectangular lines more or less distinctly indicated. These are illustrated somewhat obscurely in the figures. Other sections illustrated essentially the same relations.

*Structure in dissected crystals.*—As has been stated, the external form of the thinolite crystals seldom gives the true crystalline form. The process of dissection, however, which has laid bare the skeleton-like ribs which have been described, sometimes results in showing the true pyramidal form of the original mineral. In such cases we may have a series of skeleton crystals, each a hollow pyramid as a cap to the one preceding. This is shown in Fig. 9, which will explain itself, and again in Fig. 10 (both natural size). In another case a mass of the calcareous tufa, showing little structure, has its surface partially covered with pyramidal crystals an inch in length. Each one was a skeleton crystal inclosing a pyramidal crystal, and sometimes several crystals, after the fashion of a nest of pill-boxes. The outer surface of the crystals was incrusted with a moss-like covering, often entirely hiding the form. Two of these are represented in Figs. 16 and 17 (natural size), and another in Fig. 29, Plate III.

## THINOLITE FROM MONO LAKE.

The thinolite from the shores of Mono Lake conforms in all essential respects to that which has been described from Pyramid Lake, although on a superficial examination it presents a somewhat different aspect. It belongs in general to the more compact variety, although the same skeleton character appears on the cross fracture, and occasional specimens are nearly as open and porous as those from the Marble Buttes. The common color is light gray to nearly white. Many of the specimens consist of groups of elongated crystals, in which each crystal is built up of an indefinite number of sub-individuals bundled together in parallel position, each of these having an acute pyramidal form more or less dis-

tinct. This is shown in Figs. 19 and 20, Plate III, and even more clearly in Fig. 21; Fig. 24 also shows something of it (all natural size). Groups of sharp, almost acicular crystals in widely divergent positions are also common, and their surfaces are generally studded with rounded warty elevations of subsequently deposited calcium carbonate (see Figs. 23 and 24). The substance of these crystals is frequently perfectly firm and compact, as much so as a very fine-grained white marble, and no evidence of the characteristic structure is seen until a cross-section is cut and polished. In other cases the groups of crystals are so thickly coated with the subsequent deposit that they appear like a mass of stalactites rather than crystalline forms. On the other hand, a cross-section of a composite group of minute parallel crystals, like that in Fig. 21, shows the same open system of rectangular and diagonal ribs represented in Plate II. Fig. 22 represents a section from the extremity of the specimen shown in Fig. 21, both ends of which were sawn across transversely.

## THINOLITE FROM WALKER LAKE, AND FROM BLACK ROCK AND SMOKE CREEK DESERTS.

As has already been stated, Mr. Russell has found evidence of a second deposit of thinolite in the Lahontan basin subsequent to the formation of the dendritic tufa. This deposit was apparently only of limited extent. The localities noted are on the shores of Walker Lake and in the Black Rock and Smoke Creek deserts. A few specimens have been placed in the hands of the writer. The specimen from Walker Lake is a little obscure and exhibits the characteristic forms with much less distinctness than the specimens from Pyramid Lake. Many of the crystals have lost their original shape entirely, and others are only faintly suggestive of the square pyramidal form. There are enough, however, which do show this to remove all doubt as to the correctness of identification.

The specimens from the Black Rock Desert are peculiar, in that the nucleus of thinolite crystals passes into a dense stony tufa, which forms a cluster of rosettes about it somewhat like a head of cauliflower. This is shown in Fig. 18 (reduced one-half). The crystals offer no points of special interest, but exhibit the characteristic form distinctly enough.

## ORIGINAL CRYSTALLINE FORM OF THE THINOLITE.

The description of the specimens of thinolite given has revealed clearly the crystalline form of the original mineral. Distinct crystals, showing the external form sharply, are, to be sure, rare, but there are many which suggest this form. What is wanting in them, however, is made good by the wonderful process of dissection which has gone on, revealing, as perfectly as could be desired, the true crystalline structure of the original mineral.

All of the forms observed conform to an acute tetragonal pyramid. The section in Fig. 2, showing the system of parallel plates at right angles to each other, is alone evidence that the original crystals belonged to an orthometric system; and further, the diagonal lines, also crossing each other at right angles, fix this system as the tetragonal. The external form, wherever distinct, agrees with this (see Fig. 7; also Figs. 9, 10, 16, 17, 29); so that the question may be considered as definitely settled beyond all reasonable doubt. A form approximating closely to the tetragonal, but belonging to a system of lower symmetry, would also answer the conditions; but everything seems to point to the fact that both the sets of diagonal ribs shown in the figures are similar crystallographic lines, and that the same is true of both sets of rectangular ribs, which can be the case only in the tetragonal system. The measurement of angles leads to the same conclusion, but only an approximate degree of accuracy is attainable. If attention were directed alone to the external pyramidal form, many exceptions seemingly at variance with the tetragonal system might be observed. Many of the pyramidal forms are flattened in the direction of one of the diagonals. This is true both of the skeleton forms and of those which have been rounded out by subsequent deposition. In the former case the explanation is simply that in the direction of one of the diagonals more of the crystal has been dissolved away than in the other, and when this has first happened, and then calcium carbonate has been deposited upon the skeleton, the result has been to produce a form looking like an orthorhombic or monoclinic pyramid, with a wide difference in the pyramidal angle.

The terminal angle of the ideal square pyramid, to which the thinolite is to be referred, can be measured only approximately. The measurement of the external forms of the crystals is extremely uncertain, because the alteration which has taken place, as noted above, has naturally had the result of changing the dimensions of the original form widely. The measurement of the angle given by the structure lines, as shown in Fig. 5, is more reliable, but is also uncertain because of their want of sharpness, and because of the doubt as to whether the longitudinal section has been cut exactly parallel to the vertical axis or somewhat inclined to it. The results given by such forms as those in Figs. 9 and 10 seem a little more trustworthy, but those, too, do not admit of exact measurement. The angle obtained in a number of cases from such dissected crystals, measured over the summit, varied from 26° to 36°, and some forms were even more acute. The most probable result, perhaps, is 35° which, as nearly as can be measured, is the angle of the structure plates, as shown in Fig. 5. In any case the result can be considered as but a mere approximation.

The ideal form, then, may be accepted as that of a tetragonal pyramid or octahedron, measuring over the summit 35°, and consequently having a terminal pyramidal angle of 95¼° and a basal angle of 145°.

The corresponding length of the vertical axis is $c=2.24$. It is very probable that two or more acute pyramids, all referable to the same fundamental form, were present in the original crystals; the measurements seem to point to this, and the analogous pseudomorphs after phosgenite, mentioned later, certainly show this variation.

It has already been stated that in all the larger elongated crystals the pyramidal structure is developed in one direction only, this being true even in cases like that of Fig. 4, where the external form would suggest that the crystal had a double termination. The small crystals, however, which have grown more freely, many of them attached in the middle, seem to be complete at both extremities, although the evidence gained of this is not absolutely conclusive.

## CHEMICAL NATURE OF THE ORIGINAL MINERAL.

The description of the original crystalline form of the thinolite, so far as it can be made out, is sufficiently complete to give an emphatic negative answer to the question as to the nature of the original mineral. It was *not* gaylussite, nor gypsum, nor anhydrite, nor celestite, nor glauberite, nor, in fact, any one of the minerals which might suggest itself as a solution of the problem. The crystalline form is totally irreconcilable with any one of these. This is so clear, from what has gone before, that the question admits of no argument at all. But more can be said: the original mineral was one which does not appear thus far to have been observed in its natural condition, although, as will be shown later, it probably has occurred abundantly at numerous other localities. Furthermore, a review of all the artificial salts of calcium, sodium, and magnesium has failed to bring to light any one which would satisfy the conditions required.

It seems, therefore, that any explanation of the original condition of the thinolite beds of Lake Lahontan must, at present, rest on hypothetical grounds, and much as a definite solution of the problem is to be desired, it is not now attainable. A few suggestions may not be out of place here, although the full discussion of the subject belongs rather to the geologist who has the whole subject in charge. The open skeleton forms, consisting now of crystallized calcium carbonate, make it seem very probable that the original mineral was a double salt, and that a salt containing calcium carbonate as one of its members. Only on such a supposition is it easy to understand the removal of so large a part of the original material and the leaving behind of these plates of calcium carbonate, marking the original crystalline structure. Whether the original crystals were or were not solid throughout, at the time of their formation, it is not possible to say now with certainty; very probably they varied much at different points in this respect. From the analogy of soluble

salts deposited rapidly from aqueous solutions, it seems likely that open, cavernous forms were common, perhaps the rule. But even supposing this to be true, no one can inspect such groups of skeleton crystals as those from the Marble Buttes without seeing that what now remains is only a part of what originally crystallized out of the saline waters of Lake Lahontan. This fact, coupled with the other just mentioned, that the remaining skeleton consists of crystallized calcite in granular form, gives a very important hint as to the changes which these crystalline beds have undergone. The successive steps may have been as follows: (1) The deposition of crystals as the lake waters evaporated; (2) a change of conditions, *e. g.*, an addition of fresh water to the lake (as supposed by King), leading to the solution of a part of the substance of the crystals and the simultaneous recrystallization of the remaining calcium carbonate; (3) the subsequent and independent deposition of the carbonate, solidifying and coating over the skeleton forms. The conclusion reached by Mr. King[4] that the original mineral was gaylussite satisfies the requirements tolerably well, for it is then necessary only to explain the removal of the sodium carbonate, and the calcium carbonate remains behind. Unfortunately for this hypothesis, it is impossible to reconcile the forms which now remain, showing how the original mineral crystallized, with the monoclinic form of gaylussite.[5] Furthermore, Mr. Russell finds other grounds, independent of this crystallograpic proof, for the belief that the supposed enormous deposit of gaylussite could not have taken place. But if not gaylussite, what was the original mineral?

It is hardly profitable to go beyond the above suggestion, that it may have been a double salt, containing $CaCO_3$, unless the hypothesis can be based upon some observed facts; but fortunately some facts can be pointed to which lead to a possible explanation of the enigma, and which are in any case very suggestive.

The only crystalline forms bearing any close resemblance to the acute tetragonal pyramids of the thinolite, of which the writer has any knowledge, are those of the *pseudomorphs of lead carbonate after phosgenite*,

[4] Geological Exploration of the Fortieth Parallel, Vol. I, p. 517.

[5] At the time when Mr. King had this subject under investigation he submitted several specimens to the writer for inspection, and he then gave a qualified assent to the conclusion Mr. King had reached in regard to them. One of these specimens, as Mr. King had noted, showed some crystals which bore a remarkably close resemblance to the well known Sangerhausen pseudomorphs, then generally referred to gaylussite. This similarity suggested identity of origin—a conclusion which (after a further study of the same specimen) the present investigation has confirmed, as noted below—and thus gave apparent support to the gaylussite hypothesis. The other specimens then in hand were somewhat like Fig. 1, on Plate II, and upon the inspection given them—no opportunity was had for careful study—they gave negative results; a certain outward similarity to the elongated crystals of gaylussite from South America (called *clhros*, nails) was noted, but nothing more definite.

first described by Krug von Nidda,[6] from the zinc mines in Upper Silesia. This similarity in habit and angle is the more striking, as the thinolite form is an unusual one. A number of these pseudomorphs are in the Blum collection, which became the property of the Yale Mineralogical Museum in 1872. They correspond to the description given by Krug von Nidda. They have the form of a square prism, sometimes terminated by a pyramid having an angle over the extremity of about 36°, and occasionally show traces of an octagonal pyramid; other forms show only a very acute square octahedron, with a summit angle of about 13° in one case and 26° in another. One specimen shows these forms imbedded in a white clay. They are now completely altered to compact, fine-granular lead carbonate, except for the presence of an occasional minute nucleus of the original mineral.

The hypothesis to which this resemblance leads is this: that *the original mineral may have been a chloro-carbonate of calcium isomorphous with phosgenite*; that is, a mineral having the composition $CaCO_3+CaCl_2$ isomorphous with $PbCO_3+PbCl_2$, and now altered to $CaCO_3$ as is the phosgenite to $PbCO_3$. The hypothesis, as far as the crystallographic relations are concerned, is a most natural one. The difficulty arises when we consider the peculiar nature of calcium chloride, and hence question whether an anhydrous molecular compound of calcium carbonate and calcium chloride could have been deposited from the waters of Lake Lahontan. Obviously this is a subject for synthetic experiment, and whatever the nature of the original mineral, it ought to be possible to approximate to the conditions under which it was made and so to reproduce it. It is to be hoped that the work now being carried forward by the chemists of the Geological Survey may lead to some decisive results in this direction.

In the mean time it is interesting to note the only case in which, so far as the writer can ascertain, a chloro-carbonate of calcium has been formed. The experiments are described by Fritzsche in the Bulletin of the St. Petersburg Academy, iii, 285, Nov. 30, 1860, and reprinted in the Journal für praktische Chemie.[7] He states that on evaporating the solution of crystallized calcium chloride, prepared in large quantities for technical purposes, there remained a small amount of a sandy powder, which kept a yellowish aspect so long as the calcium chloride solution was concentrated, but in a dilute solution became finally white. When some of the crystals were placed on a glass slide under the microscope, and then water poured upon them, it was observed that they for a moment were completely transparent and underwent no change; soon, however, the surface became clouded, and then a granular separation took place gradually. As the $CaCl_2$ was dissolved they entirely lost their

[6] Krug von Nidda: Ueber das Vorkommen des Hornbleierzes und des Weissbleierzes in den Krystallformen des ersteren in Oberschlesien, Zeitsch. geol. Gesellsch. ii, 126, 1850. See also Blum, Pseudomorphosen, Zweiter Nachtrag, 68.

[7] J. Fritzsche: Ueber ein Doppelsalz aus kohlensaurem Kalk und chlorcalcium, Journ. prakt. Chem., lxxxiii, 213, 1861.

transparency, and finally there remained *only a skeleton of calcium carbonate corresponding in form and size to the original crystal.* These fell to pieces when touched, and there resulted minute spherical masses of probably amorphous carbonate. This salt was found to have the composition $2CaCO_3+CaCl_2+6H_2O$. The crystals were shown by v. Kokscharof to belong either to the orthorhombic or monoclinic system. It is not to be supposed that this salt of Fritzsche is in any way an explanation of the thinolite enigma, and yet his observations are of great interest in this connection. In order to complete the subject the fact may be noted that Berthier[8] speaks of forming a compound of calcium carbonate and chloride by fusion.

Another hypothesis may be offered as to the composition of the original mineral, viz, that it was a double salt of calcium and sodium, perhaps conforming to the formula $CaCO_3+NaCl$, or better $CaCO_3+2NaCl$, which, it is possible, might also be isomorphous with phosgenite. This is so purely hypothetical that very little weight can be given to it; still it may not be entirely useless to throw out the suggestion, although various serious objections at once come up to mind. In any case it must be borne in mind that carbonates and chlorides were the salts most likely to be precipitated from the lake water, and calcium and sodium were the prominent basic elements at hand.

## RELATION OF THE THINOLITE TO THE SO-CALLED GAYLUSSITE PSEUDOMORPHS OF SANGERHAUSEN AND OTHER LOCALITIES.

The interest connected with the thinolite is much increased by the fact of its relation to the well-known "barleycorn" pseudomorphs from Obersdorf, near Sangerhausen, in Thuringia, one of the most remarkable and enigmatical cases of pseudomorphs ever recorded. These crystals were first described by Freiesleben[9] in 1827, and at that time referred by Breithaupt[10] to gaylussite. They were early called "natrocalcite" on the mistaken idea that they contained soda. This conclusion has been accepted by most authors since that time, although Des Cloizeaux,[11] in 1843, referred them to the variety of celestite called by Haüy *apotome*, and Kenngott,[12] in 1870, suggested that gypsum might be the original mineral, and Groth,[13] in 1878, suggested anhydrite. The Sangerhausen

[8] Berthier: Ann. Chim. Phys., II, xxxviii, 253, 1828.

[9] Freiesleben: Isis, xx, 335 *et seq.*, 1827. Mag. Orykt. Sachsen, No. 7, 118 *et seq.*, 1836 (quoted by Blum).

[10] Breithaupt: Mag. Orykt. Sachsen, No. 7, 287, 1836 (quoted by Blum).

[11] Des Cloizeaux: Déterminations des formes primitives et secondaires de la Gaylussite. Ann. Chim. Phys., III, vii, 489, 1843. Observations sur la calcite, ib., p. 494. See also Minéralogie, ii, 119, 1874.

[12] Kenngott: Quoted by vom Rath, Poggendorff's Annalen, Erg.-Bd., v, 442, 1870.

[13] Groth: Min. Samml. Strassburg, p. 142, 1878.

pseudomorphs are described in detail in Blum's work on Pseudomorphs.[14] They occur imbedded in clay as complete crystals, either single or in complex groups formed by two or more crystals, interpenetrating each other; sometimes as many as twenty are united to form a star-shaped group. They average half an inch in length, but occasionally are 1, 2, or even 2½ inches long. The color is generally a pale yellow. They consist of a hard shell, with polished surface, smooth, except for a system of fine markings, and within contain a confused mass of loosely cohering calcite grains. They are represented in Figs. 26, 31, and 32. Dr. E. Geinitz,[15] who has made a special study of them, has observed within a series of zones of harder material parallel to the sides, rib-like, between which the loose calcite grains are inclosed. Similar pseudomorphs have been observed at a number of other localities. Haidinger[16] has described them as occurring in lake deposits in a limestone cave in the Tufna at Hermanecz, near Neusohl, Hungary. This cave contained large quantities of bone remains, especially those of cave bears, and the crystals themselves came from the skull of an *Ursus spelæus*.

G. Rose[17] announced the occurrence of similar pseudomorphous crystals at the village Kating, in the neighborhood of Tönningen, in Silesia. They were found here in marl, 6 or 7 feet under the soil, and resembled those from Sangerhausen closely, except that they did not have the smooth, hard shell; one of these is represented in Fig. 38. Still other localities are the east coast of Australia, mentioned by Volger[18] and Blum;[19] in the clay at the Krummer Horn, on the Dollart, in North Friesland, as mentioned by Vom Rath;[20] and from the Zechstein, between Amt-Gehren and Königsee, at the base of the Thuringian forest, as noted by E. E. Schmid.[21] To the above should probably be added Glendon, in New South Wales, and Astoria, Oregon, mentioned by J. D. Dana.[22] The first of these last-mentioned localities afforded in clay pseudomorphous crystals of granular crystallized calcite, dark in color, and having a rough surface, and up to 20 inches in length, but usually 3 or 4 inches; often in star-shaped groups of two, four, or more crystals. At the second were obtained crystalline forms, also of compact granular calcite, and of an irregular quadratic or rhombic form, sometimes much

[14] Blum: Pseudomorphosen, p. 18, 1843.

[15] E. Geinitz: Studien über Mineral-Pseudomorphosen. Inaug. Diss. Stuttgart, 1876, p. 35.

[16] Haidinger: Ueber eine neue Localität von Gay-Lussit-Pseudomorphosen. Poggendorff's Annalen, liii, 142, 1841.

[17] G. Rose: Poggendorff's Annalen, liii, 144, 1841.

[18] Volger: Erde und Ewigkeit, die natürliche Geschichte der Erde, etc., p. 497, 1857, Jahrb. Min., 1864, 339.

[19] Blum: Pseudomorphosen; dritter Nachtrag, p. 13, 1863; vierter Nachtrag, p. 8, 1879.

[20] G. vom Rath: Calcitkrystalle (Freiesleben) am Dollart in Ostfrieland, Poggendorff's Annalen, cxxxv, 588, 1868.

[21] E. E. Schmid: Sitz. med.-nat. Ges. Jena, July 9, 1880.

[22] J. D. Dana: Geology, U. S. Exploring Expedition, 1849, p. 481 and p. 656.

flattened. Figs. 34, 35 (Oregon), and 36, 37 (New South Wales) are copied (reduced one-half) from those given in the report mentioned. Thin sections of both occurrences showed only a compact granular structure, nothing resembling Fig. 2 or 3. P. W. Jeremejew[23] speaks of aragonite pseudomorphs (after celestite) from the sea bottom near Archangelsk, Russia, which resemble the Sangerhausen crystals; they are brought up by the fishermen, and believed to have a remarkable healing power.

The suggestion of the probable identity of the Sangerhausen crystals with the Lake Lahontan thinolite may at first thought seem worthy of little attention. It is certainly true that the two occurrences are most diverse in many of their forms. And yet, on the other hand, it is easy to find crystals of thinolite which bear a marvelously close resemblance to the Sangerhausen pseudomorphs. In the confused mass of small interpenetrating crystals, which have been described as coming from the Marble Buttes, Pyramid Lake, many of the individuals have the same quadratic or rhombic section, the same curved and tapering form, and the same method of grouping. Among the crystals from Mono Lake, too, are many which have a like resemblance. One specimen in particular, collected by Mr. King from Pyramid Lake, exhibits the similarity most strikingly; it was this specimen which, as already mentioned, had most weight in leading Mr. King to his conclusion (*l. c.*, p. 518) that "the entire thinolite formation, with all its enormous development, its extent of hundreds of miles, its thickness of 20 to 150 feet, was nothing less than a gigantic deposit of gaylussite crystals." This specimen shows a number of acute tapering pyramidal crystals closely resembling the Sangerhausen crystals. Two of these, which project into a little cavity, are represented in Figs. 27 and 28. The larger of these is nearly square in section, and the other is distinctly rhombic; both of them show on their surface markings similar to those which characterize the Thuringian pseudomorphs, as shown in Figs. 32 and 33. It should be added, too, that in the groups of crystals from Mono Lake are to be found some which have a hard, shell-like exterior, and which bear similar markings. These are, in the opinion of the writer, not striations characteristic of the original mineral (as suggested by Des Cloizeaux), but structure forms of the pseudomorphous calcite, analogous to the vicinal prominences of scalenohedral or rhombohedral form, which calcite crystals often show. Compare the figures given by Scharff[24] in his memoir on calcite; compare also Figs. 25 and 33 with 26; also 27, 28, and 30 with 31 and 32.

Were a comparison, then, to be made only between these pseudomorphs and certain selected crystals of thinolite, exceptional in their perfection

[23] P. W. Jeremejew: Zeitsch. Kryst., vii, 204 (Verhandl. Russ. Min. Ges St. Pet., II, xvii, 319, 1882).

[24] Scharff: Ueber den inneren Zusammenhang der verschiedenen Krystallgestalten des Kalkspaths. Abhandl. Senck. nat. Ges. x, 1876.

of form, no one could hesitate to decide that there was every probability of their having had the same origin, especially when it is remembered that chemically they are identical. This conclusion is not invalidated by the fact that the thinolite crystals are developed in other forms in which this resemblance is not observable. It may be objected that it is difficult to believe that the original mineral, in the case of the Sangerhausen pseudomorphs, for example, belonged to the tetragonal system. It is true that many of these crystals are most decidedly rhombic in appearance. One in the writer's hands, for example, afforded approximate terminal pyramidal angles of 85° and 127°; but, on the other hand, of the crystals which the writer has had an opportunity to examine—upwards of fifty in number—three-fourths vary but little from the tetragonal type. Of course no trustworthy measurements are possible, because of the tapering, rounded form. The differences observed, then, are believed to be due to the pseudomorphous process through which they have passed, involving the solution and removal of part of the original substance and the deposition of more or less calcium carbonate subsequently. The variation from the tetragonal type in the acute pyramidal forms of the thinolite is as great as in the foreign crystals which they so closely resemble, and the true form of the former would be doubtful were it not for the dissected crystals in which the tetragonal structure is so clearly shown. Note here the observations of Dr. E. Geinitz on Sangerhausen crystals (p. 26) showing the presence of ribs within parallel to the sides; these appear to be analogous to the ribs as shown in Figs. 2 and 3, etc.

The writer is of the opinion, then; that the original mineral, deposited on an enormous scale in the Lahontan Basin, was, in all probability, the same as that which formed the isolated crystals in the Sangerhausen clay, in the marl at Kating, and in the skull of the cave bear at Hermanecz; and if this is the case, then whatever hypothetical conclusion is reached in regard to the origin of the thinolite must apply also to the other cases. It is on this account that, in view of the importance of the subject under discussion, it has seemed worth while to consider these foreign pseudomorphs at such length. Unfortunately this most interesting problem can be considered as only half solved.

In concluding this paper the writer would express his appreciation of the kindness with which Mr. Russell has assisted him at every point in his investigations.

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## PLATE II.

FIG. 1. Group of thinolite crystals from Marble Buttes, Pyramid Lake (reduced one-half); open porous variety.

FIGS. 2 and 3. Transverse sections, natural size; Fig. 2, open skeleton form; Fig. 3, partially filled up with amorphous $CaCO_3$. These sections show the system of rectangular (square) and diagonal ribs, which consist of granular crystalline $CaCO_3$.

FIG. 4. External appearance (reduced one-half) of a single crystal, with part of a second, the internal structure of which shows that it has but a single termination; the comparatively smooth surface is due to the secondary deposition of $CaCO_3$.

FIG. 5. Longitudinal section of open variety (reduced one-half), showing the two systems of plates converging upward at an angle of about 35°.

FIG. 6. Complete crystal (reduced one-half) which yielded the section in Fig. 2; the line in which the section was made is indicated.

FIG. 7. Acute pyramidal crystal (reduced one-half) which yielded at its base the section given in Figure 3.

FIG. 8. Square pyramidal crystal (reduced one-half) which gave, at the point indicated, the section in Figure 13; the surface has been made smooth by subsequent deposition of $CaCO_3$.

FIGS. 9 and 10. Skeleton crystals (natural size) showing cap-in-cap structure, and thus revealing the true square pyramidal form of the original mineral.

FIG. 11. Crystals (natural size) from the Domes, Pyramid Lake; the surface smoothed over by subsequent depositions of $CaCO_3$, with sproutings from the edges and extremities.

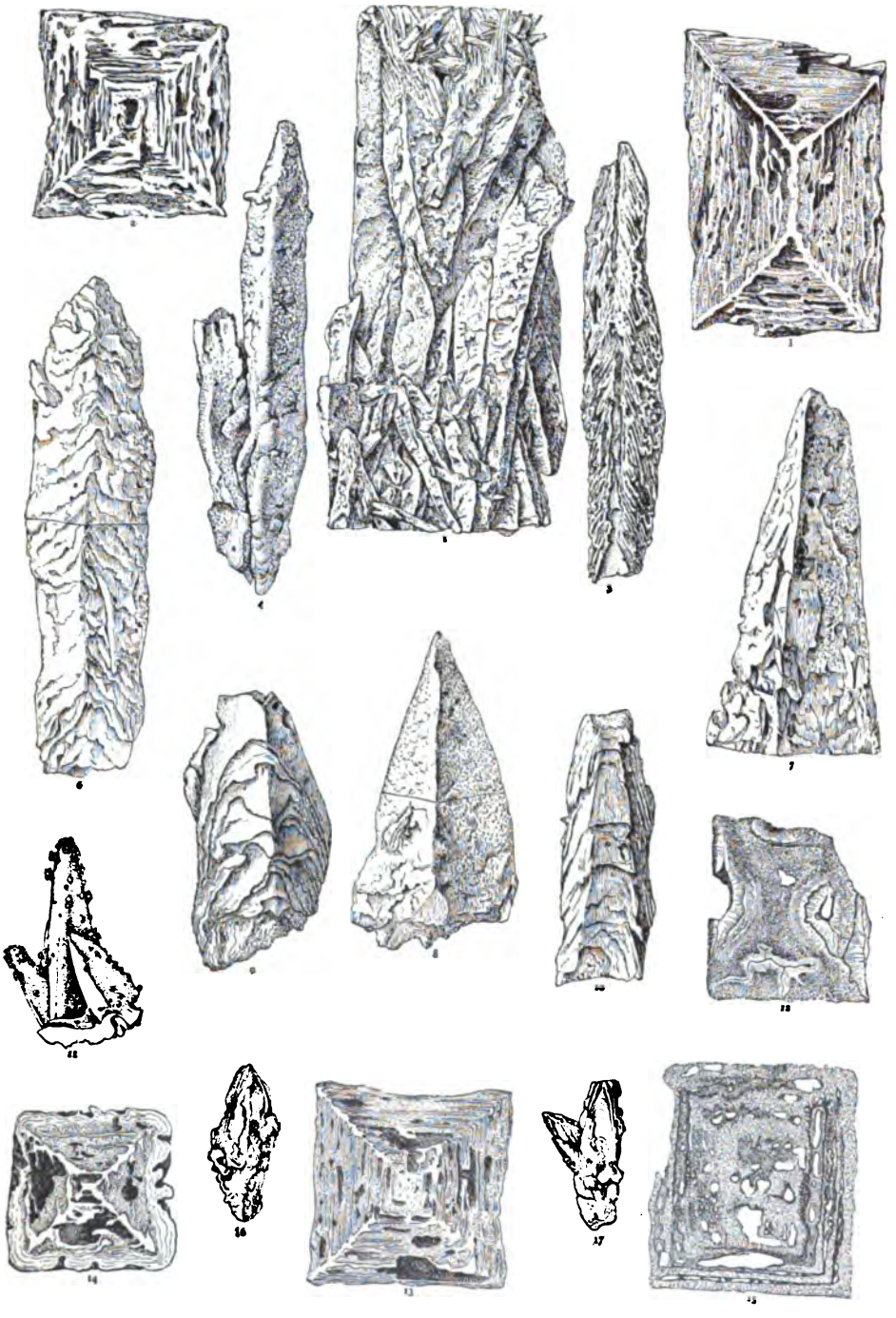
FIG. 12. Section (magnified 8 times) of a crystal from the Domes, like that in Figure 11, showing a diagonal and rectangular frame-work, partly crystalline, granular, partly amorphous, with layers of secondary carbonate opal-like in structure.

FIG. 13. Section (natural size) of the crystal shown in figure 8, cut transversely at point indicated; it shows the same frame-work of granular crystalline carbonate, partially filled in with secondary $CaCO_3$.

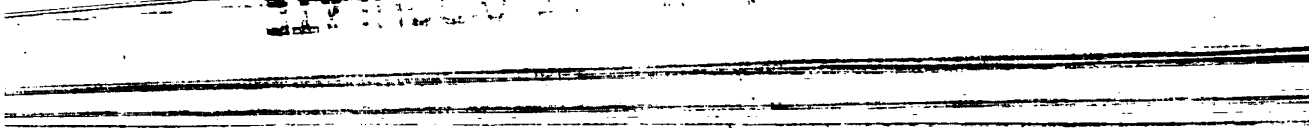
FIG. 14. Section (natural size) showing the usual frame-work, partially filled in with secondary $CaCO_3$, and with successive layers also around the outside.

FIG. 15. Section of a crystal from the Marble Buttes, magnified 8 times, and showing the structure lines of crystallized carbonate, and also in the cavities the acicular crystals of aragonite. (?)

FIGS. 16 and 17. Small pyramidal crystals (natural size), showing by dissection the cap-in-cap structure, and thus, like Figs. 9 and 10, revealing the true pyramidal form of the original mineral.



THINOLITE CRYSTALS



## PLATE III.

FIG. 18. Thinolite from Black Rock Desert (reduced one-half), the individual crystals running off into a compact stony tufa, so that the mass from above has a cauliflower-like form.

FIGS. 19 and 20. Thinolite from Mono Lake, California (natural size), showing the grouping of the composite crystals.

FIG. 21. Thinolite from Mono Lake (natural size), fragment of a large composite crystal, made up of small acicular crystals in parallel position.

FIG. 22. Transverse section of the crystal represented in fig. 21, showing the same skeleton structure distinct in crystals from Pyramid Lake (Figs. 2, 3, etc.).

FIGS. 23 and 24. Group of thinolite crystals from Mono Lake (natural size), showing the acicular form, and also the way in which the crystals are coated over with secondary carbonate.

FIG. 25. Group of small crystals (magnified 4 times) from Mono Lake, showing the same method of grouping common in the Sangerhausen pseudomorphs, as shown in Fig. 26.

FIG. 26. Group of Sangerhausen pseudomorphs (natural size); compare Fig. 25.

FIGS. 27 and 28. Isolated thinolite crystals (magnified twice), showing resemblance in form and surface marking to Sangerhausen crystals; compare Figs. 31 and 32.

FIG. 29. Thinolite crystal (natural size), showing cap-in-cap pyramidal structure, similar to Figs. 16 and 17, Plate II.

FIG. 30. Thinolite crystal (magnified 4 times), showing resemblance in form to the Sangerhausen pseudomorphs; compare with Figs. 31, 32, and 38.

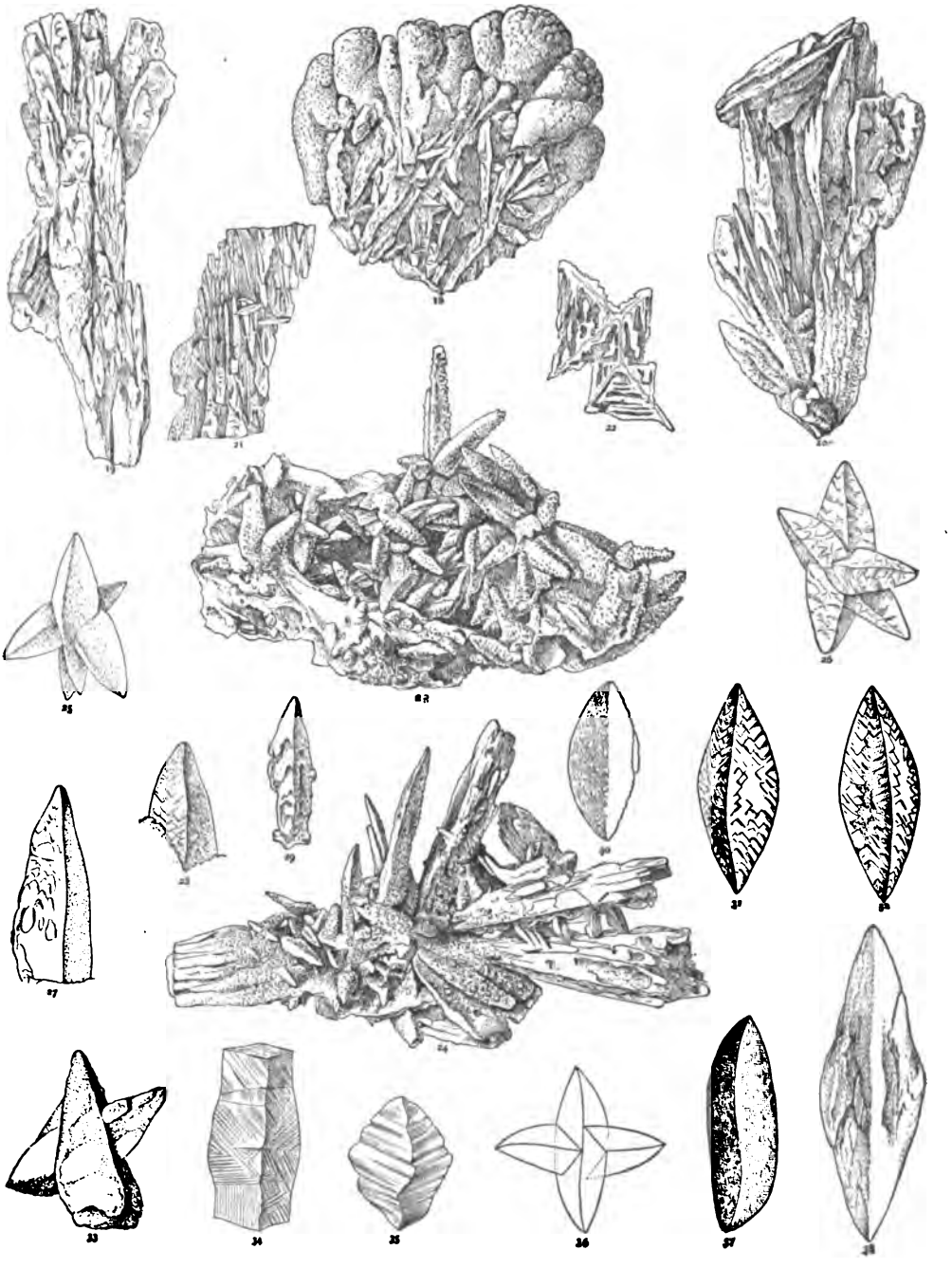
FIGS. 31 and 32. Single Sangerhausen crystals, showing form and external markings; fig. 31, natural size; Fig. 32, magnified twice.

FIG. 33. Group of small thinolite crystals (magnified 4 times); compare with Fig. 26

FIGS. 34 and 35. Pseudomorphous crystals, consisting of granular calcite from Astoria, Oregon, copied (reduced one-half) from figures by J. D. Dana in the Geology of U. S. Exploring Expedition, p. 656.

FIGS. 36 and 37. Pseudomorphous crystals, consisting of granular calcite, from New South Wales; copied (reduced one-half) from figures by J. D. Dana in the Geology of the U. S. Exploring Expedition, p. 481.

FIG. 38. Pseudomorphous crystal from Kating, Silesia (natural size).



THINOLITE CRYSTALS

# ADVERTISEMENT.

[Bulletin No. 13.]

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The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

## ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. 1882. 8°. lv, 568 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

## MONOGRAPHS

So far as already determined upon, the list of the Monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. Published.

IV. Comstock Mining and Miners, by Eliot Lord. Published.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. Published.

VI. Older Mesozoic Flora of Virginia, by Prof. William M. Fontaine. Published.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. Published.

VIII. Paleontology of the Eureka District, Nevada, by Charles D. Walcott. In press.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greens and Marls of New Jersey, by R. P. Whitfield. In press.

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

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# BOUNDARIES

OF

# THE UNITED STATES

AND OF THE

# SEVERAL STATES AND TERRITORIES

WITH A

## HISTORICAL SKETCH OF THE TERRITORIAL CHANGES

BY

HENRY GANNETT

CHIEF GEOGRAPHER

WASHINGTON

GOVERNMENT PRINTING OFFICE

1885

## LETTER OF TRANSMITTAL.

---

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
*Washington, D. C., October* 16, 1884.

SIR: I have the honor to submit herewith a sketch of the boundaries of the United States, the several States, and the Territories, as defined by treaty, charter, or statute.

Besides giving the present status of these boundaries, I have endeavored to present an outline of the history of all important changes of territory, with the laws appertaining thereto.

This matter was in great part prepared under the direction of the Superintendent of the Census, and it is herewith presented for publication with his full concurrence.

I have been greatly assisted in this work by Mr. Franklin G. Butterfield, who was formerly connected with the Census Office, by whose labors most of the material relating to the boundaries of the States upon the Atlantic borders has been compiled.

Very respectfully, yours,

HENRY GANNETT,
*Chief Geographer.*

Hon. J. W. POWELL,
*Director.*

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# CHAPTER I.

## BOUNDARIES OF THE UNITED STATES, AND ADDITIONS TO ITS TERRITORY.

### BOUNDARIES OF THE UNITED STATES.

The limits of the United States were first definitely laid down in the provisional treaty made with Great Britain in 1782. The second article of that treaty defines the boundary between the United States on the one hand and the British Possessions on the other, as follows:

From the northwest angle of Nova Scotia, viz, that angle which is formed by a line drawn due north from the source of St. Croix river to the highlands; along the Highlands which divide those rivers that empty themselves into the river St. Lawrence, from those which fall into the Atlantic Ocean, to the northwesternmost head of Connecticut River; thence down along the middle of that river to the forty-fifth degree of north latitude; from thence, by a line due west on said latitude until it strikes the river Iroquois or Cataraquy (St. Lawrence); thence along the middle of said river into Lake Ontario, through the middle of said lake until it strikes the communication by water between that lake and Lake Erie; thence along the middle of said communication into Lake Erie, through the middle of said lake until it arrives at the water communication between that lake and Lake Huron; thence along the middle of said water communication into the Lake Huron; thence through the middle of said lake to the water communication between that lake and Lake Superior; thence through Lake Superior northward of the Isles Royal and Phelippeaux to the Long Lake; thence through the middle of said Long Lake, and the water communication between it and the Lake of the Woods, to the said Lake of the Woods; thence through the said lake to the most northwestern point thereof, and from thence on a due west course to the river Mississippi; thence by a line to be drawn along the middle of the said river Mississippi until it shall intersect the northernmost part of the thirty-first degree of north latitude. South by a line to be drawn due east from the determination of the line last mentioned, in the latitude of thirty-one degrees north of the Equator, to the middle of the river Apalachicola or Catahouche; thence along the middle thereof to its junction with the Flint River; thence strait to the head of St. Mary's River; and thence down along the middle of St. Mary's River to the Atlantic Ocean. East by a line to be drawn along the middle of the river St. Croix, from its mouth in the Bay of Fundy to its source, and from its source directly north to the aforesaid highlands which divide the rivers that fall into the Atlantic Ocean from those which fall into the river St. Lawrence; comprehending all islands within twenty leagues of any part of the shores of the United States, and lying between lines to be drawn due east from the points where the aforesaid boundaries between Nova Scotia on the one part and East Florida on the other, shall respectively touch the Bay of Fundy and the Atlantic Ocean; excepting such islands as now are, or heretofore have been within the limits of the said province of Nova Scotia.

The boundary between the United States and the Spanish Possessions, known as the Floridas, is reaffirmed in the treaty between the United States and Spain, made in 1795, in the following terms:

The southern boundary of the United States, which divides their territory from the Spanish colonies of East and West Florida, shall be designated by a line beginning on the river Mississippi, at the northernmost part of the thirty-first degree of latitude north of the equator, which from thence shall be drawn due east to the middle of the river Apalachicola or Catahouche, thence along the middle thereof to its junction with the Flint; thence straight to the head of St. Mary's River, and thence down the middle thereof to the Atlantic Ocean.

The definitive treaty of peace with Great Britain, concluded September 3, 1783, defines the boundaries of the United States in terms similar to those of the provisional treaty.

The northern boundary became at once a fruitful source of dissension between the two countries. From the time of the conclusion of peace almost up to the present day this line has been the subject of a series of treaties, commissions, and surveys for the purpose of interpreting its terms.

The following is in outline a history of the settlement of this boundary:

The fourth article of the treaty of London, signed November 19, 1794, provided that—

Whereas it is uncertain whether the river Mississippi extends so far to the northward as to be intersected by a line to be drawn due west from the Lake of the Woods in the manner mentioned in the treaty of peace between His Majesty and the United States, etc., the two parties will proceed by amicable negotiation to regulate the boundary line in that quarter.

This matter was not settled, however, until 1818.

The fifth article of the same treaty makes provision for settling another doubtful point, as follows:

Whereas doubts have arisen what river was truly intended under the name of the river St. Croix mentioned in the said treaty of peace, and forming a part of the boundary therein described, that question shall be referred to the final decision of commissions to be appointed in the following manner, viz.

Here follow provisions that His Majesty and the President of the United States should each appoint a commissioner, and that these two commissioners should agree on a third, or, they failing to agree on the third, he was to chosen by lot in their presence.

Which was the true St. Croix River had been a matter of controversy between the governments of Massachusetts and Nova Scotia since the year 1764.

The commissioners appointed under the foregoing provisions decided, on the 25th October, 1798, the river called Schoodiac and the northern branch thereof (called Cheputnaticook) to be the true river St. Croix, and that its source was at the northernmost headspring of the northern branch aforesaid. A monument was erected at that spot under the direction of the commissioners. (See Memoirs of Northeastern Boundary, Gallatin, pages 7, 8.)

By the treaty of peace concluded at Ghent, December 24, 1814, it was agreed to provide for a final adjustment of the boundaries described in the treaty of 1783, which had not yet been ascertained and determined, embracing certain islands in the Bay of Fundy and the whole of the boundary line from the source of the river St Croix to the most northwestern point of the Lake of the Woods.

By article 4 provision was made for a board of commissioners to settle the title to several islands in the Bay of Passamaquoddy, which is a part of the Bay of Fundy, and the island of Grand Menan in the said Bay of Fundy.

The fifth article made provision for a board of commissioners to settle the boundary from the source of the river St. Croix northward to the highland which divides those waters that empty themselves into the river St. Lawrence from those which fall into the Atlantic Ocean, thence along said highlands to the northwesternmost head of Connecticut River, thence down along the middle of that river to the forty-fifth degree of north latitude, thence due west on said latitude until it strikes the river Iroquois or Cataraquy (St. Lawrence).

The sixth and seventh articles provided for commissioners to continue the line to the northwestern point of the Lake of the Woods.

(For further details see treaty, Statutes at Large, vol. 8, pages 220–2.)

It was provided by this treaty that in case any of the boards of commissioners were unable to agree, they should make separately or jointly a report or reports to their respective Governments stating the points on which they differed, the grounds on which they based their respective opinions, etc.

These reports were to be referred to some friendly sovereign or state for arbitration.

The first and third boards of commissioners above mentioned came to an agreement, and those portions of the boundary were thus finally settled; but the commission appointed under the fifth article, after sitting nearly five years, could not agree on any of the matters referred to them, nor even on a general map of the country exhibiting the boundaries respectively claimed by each party. They accordingly made separate reports to their Governments, stating the points on which they differed and the grounds upon which their respective opinions had been formed.

The first of these commissions awarded Moore, Dudley, and Frederick Islands to the United States, and all other islands in the Passamaquoddy Bay, and the island of Grand Menan, to Great Britain.

The following is the text of the report of the third of these commissions which had under consideration that portion of the northern boundary between the point where the forty-fifth parallel of north latitude strikes the St. Lawrence and the point where the boundary reaches Lake Superior:

Decision of the commissioners under the sixth article of the treaty of Ghent, done at Utica, in the State of New York, 18th June, 1822.

We do decide and declare that the following-described line (which is more clearly indicated on a series of maps accompanying this report, exhibiting correct surveys and delineations of all the rivers, lakes, water communications, and islands embraced by the sixth article of the treaty of Ghent, by a black line shaded on the British side with red and on the American side with blue; and each sheet of which series of maps is identified by a certificate, subscribed by the commissioners, and by the two principal surveyors employed by them) is the true boundary intended by the two beforementioned treaties, that is to say:

Beginning at a stone monument, erected by Andrew Ellicot, esq., in the year 1817, on the south bank or shore of the said river Iroquois, or Cataraqui (now called the St. Lawrence), which monument bears south 74° 45′ west, and is 1,840 yards distant from the stone church in the Indian village of St. Regis, and indicates the point at which the forty-fifth parallel of north latitude strikes the said river; thence running north 35° 45′ west into the river, on a line at right angles with the southern shore, to a point 100 yards south of the opposite island, called Cornwall Island; thence turning westerly and passing around the southern and western sides of said island, keeping 100 yards distant therefrom, and following the curvatures of its shores, to a point opposite to the northwest corner or angle of said island; thence to and along the middle of the main river until it approaches the eastern extremity of Barnhart's Island; thence northerly along the channel which divides the last-mentioned island from the Canada shore, keeping 100 yards distant from the island, until it approaches Sheik's Island; thence along the middle of the strait which divides Barnhart's and Sheik's Islands to the channel called the Long Sault, which separates the two last-mentioned islands from the lower Long Sault Island; thence westerly (crossing the center of the last-mentioned channel) until it approaches within 100 yards of the north shore of the Lower Sault Island; thence up the north branch of the river, keeping to the north of and near the Lower Sault Island, and also north of and near the Upper Sault, sometimes called Baxter's Island, and south of the two small islands marked on the map A and B, to the western extremity of the Upper Sault or Baxter's Island; thence, passing between the two islands called the Cats, to the middle of the river above; thence along the middle of the river, keeping to the north of the small islands marked C and D, and north also of Chrystler's Island, and of the small island next above it, marked E, until it approaches the northeast angle of Goose Neck Island; thence along the passage which divides the last-mentioned island fro mthe Canada shore, keeping 100 yards from the island to the upper end of the same; thence south of and near the two small islands called the Nut Islands; thence north of and near the island marked F, and also of the island called Dry or Smuggler's Island; thence passing between the islands marked G and H to the north of the island called Isle au Rapid Platt; thence along the north side of the last-mentioned island, keeping 100 yards from the shore, to the upper end thereof; thence along the middle of the river, keeping to the south of and near the islands called Coussin (or Tussin) and Presque Isle; thence up the river, keeping north of and near the several Gallop Isles numbered on the map 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10, and also of Tick, Tibbits, and Chimney Islands, and south of and near the Gallop Isles numbered 11, 12, and 13, and also of Duck, Drummond, and Sheep Islands; thence along the middle of the river, passing north of island No. 14, south of 15 and 16, north of 17, south of 18, 19, 20, 21, 22, 23, 24, 25, and 28, and north of 26 and 27; thence along the middle of the river, north of Gull Island and of the islands Nos. 29, 32, 33, 34, 35, Bluff Island, and Nos. 39, 44, and 45, and to the south of Nos. 30, 31, 36, Grenadier Island, and Nos. 37, 38, 40, 41, 42, 43, 46, 47, and 48, until it approaches the east end of Well's Island; thence to the north of Well's Island, and along the strait which divides it

from Rowe's Island, keeping to the north of the small islands Nos. 51. 52, 54, 58, 59, and 61, and to the south of the small islands numbered and marked 49, 50, 53, 55, 57, 60, and H, until it approaches the northeast point of Grindstone Island; thence to the north of Grindstone Island, and keeping to the north also of the small islands Nos. 63, 65, 67, 68, 70, 72, 73, 74, 75, 76, 77, and 78, and to the south of Nos. 62, 64, 66, 69, and 71, until it approaches the southern point of Hickory Island; thence passing to the south of Hickory Island and of the two small islands lying near its southern extremity, numbered 79 and 80; thence to the south of Grand or Long Island, keeping near its southern shore, and passing to the north of Carlton Island, until it arrives opposite to the southwestern point of said Grand Island, in Lake Ontario; thence, passing to the north of Grenadier, Fox, Stony, and the Gallop Islands, in Lake Ontario, and to the south of and near the islands called the Ducks, to the middle of the said lake; thence westerly along the middle of said lake to a point opposite the mouth of the Niagara River; thence to and up the middle of the said river to the Great Falls; thence up the Falls through the point of the Horse Shoe, keeping to the west of Iris or Goat Island, and of the group of small islands at its head, and following the bends of the river so as to enter the strait between Navy and Grand Islands; thence along the middle of said strait to the head of Navy Island; thence to the west and south of and near to Grand and Beaver Islands, and to the west of Strawberry, Squaw, and Bird Islands to Lake Erie; thence southerly and westerly along the middle of Lake Erie in a direction to enter the passage immediately south of Middle Island, being one of the easternmost of the group of islands lying in the western part of said lake; thence along the said passage, proceeding to the north of Cunningham's Island, of the three Bass Islands, and of the Western Sister, and to the south of the islands called the Hen and Chickens, and of the Eastern and Middle Sisters; thence to the middle of the mouth of the Detroit River in a direction to enter the channel which divides Bois Blanc and Sugar Islands; thence up the said channel to the west of Bois Blanc Island, and to the east of Sugar, Fox, and Stony Islands, until it approaches Fighting or Great Turkey Island; thence along the western side and near the shore of said last-mentioned island to the middle of the river above the same; thence along the middle of said river, keeping to the southeast of and near Hog Island, and to the northwest of and near the island Isle à la Pêche, to Lake Saint Clair; thence through the middle of said lake in a direction to enter that mouth or channel of the river St. Clair, which is usually denominated the Old Ship Channel; thence along the middle of said channel, between Squirrel Island on the southeast and Herson's Island on the northwest, to the upper end of the last-mentioned island, which is nearly opposite to Point au Chênes, on the American shore; thence along the middle of the river Saint Clair, keeping to the west of and near the islands called Belle Rivière Isle and the Isle aux Cerfs, to Lake Huron; thence through the middle of Lake Huron in a direction to enter the strait or passage between Drummond's Island on the west and the Little Manitou Island on the east; thence through the middle of the passage which divides the two last-mentioned islands; thence, turning northerly and westerly, around the eastern and northern shores of Drummond's Island, and proceeding in a direction to enter the passage between the island of Saint Joseph's and the American shore, passing to the north of the intermediate islands Nos. 61, 11, 10, 12, 9, 6, 4, and 2, and to the south of those numbered 15, 13, 5, and 1; thence up the said last-mentioned passage, keeping near to the island Saint Joseph's, and passing to the north and east of Isle à la Crosse and of the small islands numbered 16, 17, 18, 19, and 20, and to the south and west of those numbered 21, 22, and 23, until it strikes a line (drawn on the map with black ink and shaded on one side of the point of intersection with blue and on the other with red) passing across the river at the head of Saint Joseph's Island and at the foot of the Neebish Rapids, which line denotes the termination of the boundary directed to be run by the sixth article of the treaty of Ghent.

And the said commissioners do further decide and declare that all the islands lying

in the rivers, lakes, and water communications between the before-described boundary line and the adjacent shores of Upper Canada do, and each of them does, belong to His Britannic Majesty, and that all the islands lying in the rivers, lakes, and water communications between the said boundary line and the adjacent shores of the United States or their territories do, and each of them does, belong to the United States of America, in conformity with the true intent of the second article of the said treaty of 1783, and of the sixth article of the treaty of Ghent.

By the second article of the convention with Great Britain—1818—the boundary line was extended westward along the forty-ninth parallel of latitude to the "Stony" (Rocky) Mountains, while beyond these mountains the treaty provided that the country should remain open to both parties. The terms of the treaty are as follows:

ARTICLE 2. It is agreed that a line drawn from the most northwestern point of the Lake of the Woods along the forty-ninth parallel of north latitude, or if the said point shall not be in the forty-ninth parallel of north latitude, then that a line drawn from the said point due north or south, as the case may be, until the said line shall intersect the said parallel of north latitude, and from the point of such intersection due west along and with the said parallel, shall be the line of demarkation between the territories of the United States and those of His Britannic Majesty, and that the said line shall form the northern boundary of the said territories of the United States and the southern boundary of the territories of His Britannic Majesty from the Lake of the Woods to the Stony Mountains.

ARTICLE 3. It is agreed that any country that may be claimed by either party on the northwest coast of America, westward of the Stony Mountains, shall, together with its harbours, bays, and creeks, and the navigation of all rivers within the same, be free and open, for the term of ten years from the date of the signature of the present convention, to the vessels, citizens, and subjects of the two powers; it being well understood that this agreement is not to be construed to the prejudice of any claim which either of the two high contracting parties may have to any part of the said country, nor shall it be taken to affect the claims of any other power or state to any part of the said country; the only object of the high contracting parties in that respect being to prevent disputes and differences amongst themselves.

In 1824 negotiations were resumed between the two countries for the settlement, among other things, of the boundary west of the Rocky Mountains, but no conclusion was reached; the claim of the English Government being that the boundary line should follow the forty-ninth parallel westward to the point where this parallel strikes the great northwestern branch of the Columbia River, thence down the middle of that river to the Pacific Ocean.

In 1826 negotiations were resumed, and several compromises were proposed by both parties, but without satisfactory results. After this the whole matter remained in abeyance until the special mission of Lord Ashburton to this country in 1842.

Meanwhile the unsettled questions regarding the northeastern boundary again came up.

The case having reached that stage at which it became necessary to refer the points of difference to a friendly sovereign or state, the two powers found it expedient to regulate the proceedings and make provisions in relation to such reference, and on the 29th September, 1827, concluded a convention to that effect.

The respective claims of the United States and Great Britain were as follows, viz:

*Boundary claimed by United States.*—From the source of the river St. Croix (a point of departure mutually acknowledged) the boundary should be a due north line for about 140 miles, crossing the river St. John at about 75 miles. At about 97 miles it reaches a ridge or highland which divides tributary streams of the river St. John, which falls into the Bay of Fundy, from the waters of the river Ristigouche, which falls through the Bay des Chaleurs into the Gulf of St. Lawrence. In its further course the said due north line, after crossing several upper branches of the river Ristigouche, reaches, at about 140 miles, the highlands which divide the waters of the said river Ristigouche from the tributary streams of the river Metis, which falls into the river St. Lawrence.

Thence the line should run westerly and southwesterly along the highlands which divide the sources of the several rivers (from the Metis to the St. Francis) that empty themselves into the river St. Lawrence—from the sources of the tributaries of the rivers Ristigouche, St. John, Penobscot, Kennebec, and Connecticut, all which either mediately or immediately fall into the Atlantic Ocean.

*Boundary claimed by Great Britain.*—From the source of the river St. Croix the boundary should be a due north line about 40 miles to a point at or near Mars Hill; thence it should run westerly about 115 miles along the highlands that divide the sources of the tributaries of the river St. John from the sources of the river Penobscot to a spot called Metjarmette Portage, near the source of the river Chaudière.

From this point the line coincides with the line claimed by the United States until the northwesternmost head of the Connecticut River is reached. Great Britain claimed one of several small streams to be the northwesternmost tributary of the Connecticut River, and the United States another.

The King of the Netherlands was selected in 1829 by the two Governments as the arbiter, and each laid before him, in conformity with the provisions of the convention, all the evidence intended to be brought in support of its claim, and two separate statements of the respective cases. These four statements, which embrace the arguments at large of each party, respectively, have been printed, but not published (1840).

The award of the King of the Netherlands, made in 1831, was as follows, viz:

* * * * * * *

We are of the opinion that it will be suitable (*il conviendra*) to adopt as the boundary of the two states a line drawn due north from the source of the river St. Croix to the point where it intersects the middle of the thalweg of the river St. John; thence the middle of the thalweg of that river, ascending it to the point where the the thalweg of the river Saint Francis, ascending it to the source of its southwest-river St. Francis empties itself into the river St. John; thence the middle of

ernmost branch, which source we indicate on the Map A by the letter X, authenticated by the signature of our minister of foreign affairs; thence in a line drawn due west to the point where it unites with the line claimed by the United States of America and delineated on the Map A; thence said line to the point at which, according to said map, it coincides with that claimed by Great Britain, and thence the line traced on the map by the two powers to the northwesternmost source of Connecticut River.

* * * * * * *

We are of the opinion that the stream situated farthest to the northwest, among these which fall into the northernmost of the three lakes, the last of which bears the name of Connecticut Lake, must be considered as the northwesternmost head of Connecticut River.

* * * * * * *

We are of the opinion that it will be suitable (*il conviendra*) to proceed to fresh operations to measure the observed latitude in order to mark out the boundary from river Connecticut along the parallel of the forty-fifth degree of north latitude to the river Saint Lawrence, named in the treaties Iroquois or Cataraquy, in such a manner, however, that, in all cases, at the place called Rouse's Point the territory of the United States of America shall extend to the fort erected at that place, and shall include said fort and its kilometrical radius (*rayon kilometrique*).

* * * * * * *

However disposed the Government of the United States might have been to acquiesce in the decision of the arbiter, it had not the power to change the boundaries of a State without the consent of the State. Against that alteration the State of Maine entered a solemn protest by the resolutions of 19th January, 1832. And the Senate of the United States did accordingly refuse to give its assent to the award.

The arbitration of the King of the Netherlands having failed, fruitless negotiations ensued for a period of eleven years. Unsuccessful attempts were made to conclude an agreement preparatory to another arbitration. The subject became a matter of great irritation, collisions occurred in the contested territory, and for a time it seemed certain that the controversy would result in war between the two powers. In 1842, however, Great Britain gave unequivocal proof of her desire for the preservation of peace, and an amicable arrangement of the matter at issue, by the special mission of Lord Ashburton to the United States. The subject of this mission was the settlement, not only of the northeastern boundary, but the northern boundary west of the Rocky Mountains. Regarding this object of his mission, Lord Ashburton's instructions gave as the ultimatum of the English Government the boundary as above sketched (p. 14), and, naturally, his mission had no result, as far as this portion of the boundary was concerned.

An agreement was reached, however, in regard to the northeastern boundary, which, the consent of the State of Maine having been obtained, was embodied in the treaty concluded August 9, 1842.

The following is the text of the portion of this treaty relating to the boundary:

ARTICLE I. It is hereby agreed and declared that the line of boundary shall be as follows: Beginning at the monument at the source of the river St. Croix, as desig-

nated and agreed to by the commissioners under the fifth article of the treaty of 1794, between the Governments of the United States and Great Britain; thence north, following the exploring line run and marked by the surveyors of the two Governments in the years 1817 and 1818, under the fifth article of the treaty of Ghent, to its intersection with the river St. John, and to the middle of the channel thereof; thence up the middle of the main channel of the said river St. John, to the mouth of the river Saint Francis; thence up the middle of the channel of the said river St. Francis, and of the lakes through which it flows, to the outlet of the Lake Pohenagamook; thence southwesterly, in a straight line, to a point on the northwest branch of the river St. John, which point shall be ten miles distant from the main branch of the St. John, in a straight line, and in the nearest direction, but if the said point shall be found to be less than seven miles from the nearest point of the summit or crest of the highlands that divide those rivers which empty themselves into the river St. Lawrence from those which fall into the river St. John, there the said point shall be made to recede down the said northwest branch of the river St. John, to a point seven miles in a straight line from the said summit or crest; thence in a straight line, in a course about south, eight degrees west, to the point where the parallel of latitude 46° 25′ north intersects the southwest branch of the St. John's; thence southerly, by the said branch, to the source thereof in the highlands at the Metjarmette portage; thence down along the said highlands which divide the waters which empty themselves into the river Saint Lawrence from those which fall into the Atlantic Ocean, to the head of Hall's stream; thence down the middle of said stream till the line thus run intersects the old line of boundary surveyed and marked by Valentine and Collins, previously to the year 1774, as the 45th degree of north latitude, and which has been known and understood to be the line of actual division between the States of New York and Vermont on one side, and the British province of Canada on the other; and from said point of intersection, west, along the said dividing line, as heretofore known and understood, to the Iroquois or St. Lawrence River.

ARTICLE II. It is moreover agreed that, from the place where the joint commissioners terminated their labors under the sixth article of the treaty of Ghent, to-wit, at a point in the Neebish channel, near Muddy Lake, the line shall run into and along the ship channel, between St. Joseph and Saint Tammany islands, to the division of the channel at or near the head of St. Joseph's Island; thence turning eastwardly and northwardly around the lower end of St. George's or Sugar Island, and following the middle of the channel which divides St. George's from St. Joseph's Island; thence up the east Neebish channel, nearest to St. George's Island, through the middle of Lake George; thence west of Jonas' Island, into St. Mary's River, to a point in the middle of that river, about one mile above St. George's or Sugar Island, so as to appropriate and assign the said island to the United States; thence, adopting the line traced on the maps by the commissioners, through the river St. Mary and Lake Superior, to a point north of Ile Royale, in said lake, one hundred yards to the north and east of Ile Chapeau, which last mentioned island lies near the northeastern point of Ile Royale, where the line marked by the commissioners terminates; and from the last-mentioned point, southwesterly, through the middle of the sound between Ile Royale and the northwestern mainland, to the mouth of Pigeon River, and up the said river, to and through the north and south Fowl Lakes, to the lakes of the height of land between Lake Superior and the Lake of the Woods; thence along the water communication to Lake Saisaginaga, and through that lake; thence to and through Cypress Lake, Lac du Bois Blanc, Lac la Croix, Little Vermillion Lake, and Lake Namecan, and through the several smaller lakes, straits, or streams, connecting the lakes here mentioned, to that point in Lac la Pluie, or Rainy Lake, at the Chaudière Falls, from which the commissioners traced the line to the most northwestern point of the Lake of the Woods; thence, along the said line, to the said most northwestern point, being in latitude 49° 23′ 55″ north, and in longitude 95° 14′ 38″ west from the observatory at Greenwich; thence, according to existing treaties, due south to its in-

terminate with the forty-ninth parallel of north latitude, and along that parallel to the Rocky Mountains. It being understood that all the water communications and all the usual portages along the line from Lake Superior to the Lake of the Woods, and also Grand Portage, from the shore of Lake Superior to the Pigeon River, as now actually used, shall be free and open to the use of the citizens and subjects of both countries.

* * * * * * *

ARTICLE VII. It is further agreed that the channels in the river St. Lawrence, on both sides of the Long Sault islands, and of Barnhart Island; the channels in the river Detroit, on both sides of the island Bois Blanc, and between that island and both the American and Canadian shores, and all the several channels and passages between the various islands lying near the junction of the river St. Clair with the lake of that name, shall be equally free and open to the ships, vessels, and boats of both parties.

Between 1843 and 1846 there was considerable negotiation regarding the boundary west of the Rocky Mountains, resulting finally in the Webster-Ashburton treaty, which defined the boundary as far west as the straits of Juan de Fuca. The following is that portion of the treaty which defines the boundary.

TREATY WITH GREAT BRITAIN, 1846.

ARTICLE I. From the point on the forty-ninth parallel of north latitude, where the boundary laid down in existing treaties and conventions between the United States and Great Britain terminates, the line of boundary between the territories of the United States and those of Her Britannic Majesty shall be continued westward along the said forty-ninth parallel of north latitude to the middle of the channel which separates the continent from Vancouver's Island, and thence southerly through the middle of the said channel, and of Fuca's Straits to the Pacific Ocean: *Provided, however*, That the navigation of the whole of the said channel and straits south of the forty-ninth parallel of north latitude remain free and open to both parties.

ARTICLE II. From the point at which the forty-ninth parallel of north latitude shall be found to intersect the great northern branch of the Columbia River, the navigation of the said branch shall be free and open to the Hudson's Bay Company, and to all British subjects trading with the same, to the point where the said branch meets the main stream of the Columbia, and thence down the said main stream to the ocean, with free access into and through the said river or rivers, it being understood that all the usual portages along the line thus described shall, in like manner, be free and open. In navigating the said river, or rivers, British subjects, with their goods and produce, shall be treated on the same footing as citizens of the United States; it being, however, always understood that nothing in this article shall be construed as preventing, or intending to prevent, the Government of the United States from making any regulations respecting the navigation of the said river or rivers not inconsistent with the present treaty.

The above treaty extended the line westward from the Rocky Mountains to the Pacific along the forty-ninth parallel of latitude. This settled the northern boundary with the exception of the islands and passages in the straits of Georgia and of Juan de Fuca, the English claiming that the boundary should properly run through the Rosario strait, the most eastern passage, while the United States claimed that it should naturally follow the Canal de Haro.

This matter was finally settled by a reference to the Emperor of Germany as an arbitrator, who decided it in favor of the United States on

the 21st of October, 1872, thus finally disposing of our boundary with Great Britain.

## ADDITIONS TO THE TERRITORY OF THE UNITED STATES.

### THE LOUISIANA PURCHASE.

The region subsequently known as the territory of Louisiana was originally claimed by France, by virtue of discovery and occupation.

In 1712 France made a grant to Antoine de Crozat, of the exclusive right to the trade of this region. As this grant makes the first, and indeed the only statement of the limits of this vast region, as they were understood by France, a portion of it is here introduced.

We have by these presents signed with our hand, authorized, and do authorize the said Sieur Crozat to carry on exclusively the trade in all the territories by us possessed, and bounded by New Mexico and by those of the English in Carolina, all the establishments, ports, harbors, rivers, and especially the port and harbor of Dauphin Island, formerly called Massacre Island, the river St. Louis, formerly called the Mississippi, from the seashore to the Illinois, together with the river St. Philip, formerly called the Missouries River, and the St. Jerome, formerly called the Wabash (the Ohio), with all the countries, territories, lakes in the land, and the rivers emptying directly or indirectly into that part of the river St. Louis. All the said territories, countries, rivers, streams, and islands, we will to be and remain comprised under the name of the Government of Louisiana, which shall be dependent on the general Government of New France, and remain subordinate to it, and we will, moreover, that all the territories which we possess on this side of the Illinois, be united, as far as need be, to the general Government of New France, and form a part thereof; reserving to ourself, nevertheless, to increase, if we judge proper, the extent of the government of the said country of Louisiana.

From this it appears that Louisiana was regarded by France as comprising the drainage basin of the Mississippi as far north as the mouth of the Illinois, with those of all its branches which enter it below this point, including the Missouri, but excluding that portion in the southwest claimed by Spain. It is moreover certain that the area now comprised in Washington, Oregon, and Idaho was not included.

Crozat surrendered this grant in 1717.

On November 3, 1762, France ceded this region to Spain, defining it only as the province of Louisiana. A few months later, on February 10, 1763, by the treaty of peace between Great Britain, France, and Spain, the western boundary of the former's possessions in the New World, was placed in the center of the Mississippi River, thus reducing the area of Louisiana by the portion east of the Mississippi River.

By the treaty of San Ildefonso, October 1, 1800, Spain transferred back to France the balance of the province of Louisiana.

Immediately after this transfer became known, which was on November 30, 1803, measures were set on foot by President Jefferson for

securing in some way free access to the sea by way of the Mississippi River. Circumstances favored this negotiation. Bonaparte was at that time in almost daily expectation of a declaration of war by Great Britain, in which case the first act of the latter would be to seize the mouth of the Mississippi, and with it the province of Louisiana. Under these circumstances Bonaparte offered to sell the province to the United States, and the offer was promptly accepted. The consideration was 60,000,000 francs and the assumption by the United States of the "French spoliation claims," which were estimated to amount to $3,750,000.

The treaty of cession, which bears date April 30, 1803, describes the territory only as being the same as ceded by Spain to France by the treaty of San Ildefonso.

From this it appears that the territory sold to the United States comprised that part of the drainage basin of the Mississippi which lies west of the course of the river, with the exception of such parts as were then held by Spain. The want of precise definition of limits in the treaty was not objected to by the American commissioners, as they probably foresaw that this very indefiniteness might prove of service to the United States in future negotiations with other powers. In fact, the claim of the United States to the area now comprised in Oregon, Washington, and Idaho in the negotiations with Great Britain regarding the northwestern boundary, was ostensibly based, not only upon prior occupation and upon purchase from Spain, but also upon the alleged fact that this area formed part of the Louisiana purchase. That this claim was baseless is shown not only by what has been already detailed regarding the limits of the purchase, but also by the direct testimony of the French plenipotentiary, M. Barbé Marbois. Some twenty years after the purchase he published a work upon Louisiana, in which he detailed at some length the negotiations which preceded the purchase, and, referring to this question said: "The shores of the western ocean were certainly not comprised in the cession, but already the United States are established there."

There is also contained in this work a map of the country between the Mississippi and the Pacific, on which the extent of Louisiana to the westward is indicated by a line drawn on the one hundred and tenth meridian, which is not far from the western limit of the drainage basin of the Mississippi in Wyoming and Montana. That part of the country now comprised in Oregon, Washington, and Idaho, which, it has been claimed, formed part of the purchase, bears the following legend: "Territories and countries occupied by the United States, following the treaty of cession of Louisiana."

From this it appears that the limits of the Louisiana purchase can no longer be a matter of discussion; but although the United States certainly did not purchase Oregon, as a part of Louisiana, it is no less

certain that that great area west of the Rocky Mountains fell into their hands as a direct consequence of such purchase.

### FLORIDA.

The second addition to the territory of the United States consisted of the Floridas, purchased from Spain on February 22, 1819. From the date of the Louisiana purchase in 1803, the territory bounded by the Mississippi River on the west, the Perdido on the east, the parallel of 31° on the north, and the Gulf on the south had been in dispute between the two countries. During this time it had been practically in the possession of the United States. This purchase settled these conflicting claims.

The following is the clause in the treaty with Spain ceding the Floridas which defines the cession:

ART. 2. His Catholic Majesty cedes to the United States, in full property and sovereignty, all the territories which belong to him, situated to the eastward of the Mississippi, known by the name of East and West Florida, the adjacent islands dependent upon said province, etc.

A further article in this treaty defines the boundary between the United States and the Spanish Possessions in the southwest, as follows:

The boundary line between the two countries, west of the Mississippi, shall begin on the Gulph of Mexico, at the mouth of the river Sabine, in the sea, continuing north, along the western bank of that river, to the thirty-second degree of latitude; thence by a line due north to the degree of latitude where it strikes the Rio Roxo of Nachitoches, or Red River; then following the course of the Rio Roxo to the degree of longitude 100 west from London, or about 23° west of Washington; then crossing the said Rio Roxo and running thence, by a line due north, to the River Arkansas; thence, following the course of the southern bank of the Arkansas, to its source in latitude 42 north; and thence by that parallel of latitude to the South Sea, the whole being as laid down in Melish's map of the United States, published at Philadelphia, improved to the 1st of January, 1818. But if the source of the Arkansas River shall be found to fall north or south of latitude 42, then the line shall run from the said source due south or north, as the case may be, till it meets the said parallel of latitude 42, and thence along the said parallel to the South Sea, all the islands in the Sabine and the said Red and Arkansas Rivers, throughout the course thus described, to belong to the United States; but the use of the waters, and the navigation of the Sabine to the sea, and of the said rivers Roxo and Arkansas throughout the extent of the said boundary on their respective banks shall be common to the respective inhabitants of both nations.

### TEXAS.

The next acquisition of territory was that of the Republic of Texas, which was admitted as a State on December 29, 1845. The area which Texas brought into the Union was limited as follows:

All the land lying east of the Rio Grande and embraced within the limits of the Rio Grande on the west and south and the boundary between the United States and Spain under the Florida treaty of 1819, on the east, viz, the Sabine River, thence north to the Red River, thence up the Red River to the one hundredth meridian west of Greenwich, thence due north to the Arkansas River, thence up the Arkansas River to its source and down the Rio Grande.

THE FIRST MEXICAN CESSION.

In 1848 a further addition was made to our territory by the treaty of Guadalupe-Hidalgo. This added to the country the area of California, Nevada, Utah, and parts of Colorado, Arizona, and New Mexico, while the Gadsden purchase, which was effected in 1853, added the remainder of Arizona and another part of New Mexico.

The treaty of Guadalupe-Hidalgo was concluded February 2, 1848, and proclaimed July 4, 1848. The clauses in it defining our acquisition of territory are as follows:

ARTICLE V. The boundary line between the two republics shall commence in the Gulf of Mexico, three leagues from land, opposite the mouth of the Rio Grande, otherwise called the Rio Bravo del Norte, or opposite the mouth of its deepest branch, if it should have more than one branch emptying into the sea; from thence up the middle of that river, following the deepest channel where it has more than one, to the point where it strikes the southern boundary of New Mexico; thence westwardly along the whole southern boundary of New Mexico (which runs north of the town called Paso) to its western termination; thence northward along the western line of New Mexico until it intersects the first branch of the river Gila (or if it should not intersect any branch of that river, then to the point on the said line nearest to such branch, and thence in a direct line to the same); thence down the middle of the said branch and of the said river until it empties into the Rio Colorado; thence across the Rio Colorado, following the division line between Upper and Lower California, to the Pacific Ocean.

The southern and western limits of New Mexico, mentioned in this article, are those laid down in the map entitled, "Map of the United Mexican States as organized and defined by various acts of the Congress of said Republic, and constructed according to the best authorities. Revised edition. Published at New York, in 1847, by J. Disturnell;" of which map a copy is added to this treaty, bearing the signatures and seals of the undersigned plenipotentiaries. And, in order to preclude all difficulty in tracing upon the ground the limit separating Upper from Lower California, it is agreed that the said limit shall consist of a straight line drawn from the middle of the Rio Gila, where it unites with the Colorado, to a point on the coast of the Pacific Ocean, distant one marine league due south of the southernmost point of the port of San Diego, according to the plan of said port made in the year 1782, by Don Juan Pantoja, second sailing-master of the Spanish fleet, and published at Madrid in the year 1802, in the atlas to the voyage of the schooners Sutil and Mexicana; of which plan a copy is hereunto added, signed and sealed by the respective plenipotentiaries.

GADSDEN PURCHASE.

Subsequently, on December 30, 1853, a second purchase was made of Mexico, consisting of the strip of land lying south of the Gila River, in New Mexico and Arizona. The boundaries as established by this, known as the Gadsden purchase, were as follows:

ARTICLE I. The Mexican Republic agrees to designate the following as her true limits with the United States for the future: Retaining the same dividing line between the two Californias as already defined and established, according to the fifth article of the treaty of Guadalupe-Hidalgo, the limits between the two republics shall be as follows: Beginning in the Gulf of Mexico, three leagues from land, opposite the mouth of the Rio Grande, as provided in the fifth article of the treaty of Guadalupe-Hidalgo; thence, as defined in the said article, up the middle of that river to the point where the parallel of 31° 47′ north latitude crosses the same; thence due west one

hundred miles; thence south to the parallel of 31° 20′ north latitude; thence along the said parallel of 31° 20′ to the one hundred and eleventh meridian of longitude west of Greenwich; thence in a straight line to a point on the Colorado River twenty English miles below the junction of the Gila and Colorado Rivers; thence up the middle of the said river Colorado until it intersects the present line between the United States and Mexico.

ALASKA.

There remains but one acquisition of territory to the United States from foreign powers, viz, that of Alaska, purchased from Russia. The treaty of purchase was signed on March 30, 1867, and proclaimed June 20, 1867. The boundaries of the territory are described in the accompanying quotation from the treaty:

Commencing from the southernmost point of the island called Prince of Wales Island, which point lies in the parallel of 54° 40′′ north latitude, and between the one hundred and thirty-first and one hundred and thirty-third degree of west longitude (meridian of Greenwich), the said line shall ascend to the north along the channel called Portland Channel as far as the point of the continent where it strikes the fifty-sixth degree of north latitude; from this last-mentioned point, the line of demarkation shall follow the summit of the mountains situated parallel to the coast, as far as the point of intersection of the one hundred and forty-first degree of west longitude (of the same meridian); and, finally, from the said point of intersection, the said meridian line of the one hundred and forty-first degree in its prolongation as far as the Frozen Ocean.

IV. With reference to the line of demarkation laid down in the preceding article, it is understood—

1st. That the island called Prince of Wales Island shall belong wholly to Russia, (now, by this cession, to the United States).

2d. That whenever the summit of the mountains which extend in a direction parallel to the coast from the fifty-sixth degree of north latitude to the point of intersection of the one hundred and forty-first degree of west longitude shall prove to be at the distance of more than ten marine leagues from the ocean, the limit between the British possessions and the line of coast which is to belong to Russia, as above mentioned (that is to say, the limit to the possessions ceded by this convention), shall be formed by a line parallel to the winding of the coast, and which shall never exceed the distance of ten marine leagues therefrom.

The western limit within which the territories and dominion conveyed are contained passes through a point in Behring's Straits on the parallel of 65° 30′ north latitude, at its intersection by the meridian which passes midway between the islands of Krusenstern or Ignalook, and the island of Ratmanoff, or Noonerbook, and proceeds due north without limitation into the same Frozen Ocean.

The same western limit, beginning at the same initial point, proceeds thence in a course nearly southwest through Behring's Straits and Behring's Sea, so as to pass midway between the northwest point of the island of Saint Lawrence and the southeast point of Cape Choukotski to the meridian of one hundred and seventy-two west longitude, thence from the intersection of that meridian in a southwesterly direction, so as to pass midway between the island of Attore and the Copper Island of the Kormandorski couplet or group, in the North Pacific Ocean, to the meridian of one hundred and ninety-three degrees west longitude, so as to include in the territory conveyed the whole of the Aleutian Islands west of that meridian.

The consideration paid for the Territory of Alaska was $7,200,000, in gold.

## CHAPTER II.

### THE PUBLIC DOMAIN AND AN OUTLINE OF THE HISTORY OF CHANGES MADE THEREIN.

#### CESSIONS BY THE STATES.

At the time the Constitution was adopted by the original thirteen States, many of them possessed unoccupied territory, in some cases entirely detached and lying west of the Appalachian Mountains. Thus, Georgia included the territory from its present eastern limits westward to the Mississippi River. North Carolina possessed a narrow strip extending from latitude 35° to 36° 30′, approximately, and running westward to the Mississippi, including besides its own present area that of the present state of Tennessee. In like manner, Virginia possessed what is now Kentucky, while a number of States, as Pennsylvania, New York, Massachusetts, and Connecticut, laid claim to areas in what was afterward known as the Territory Northwest of the River Ohio, a region which is now comprised mainly in the States of Ohio, Indiana, Illinois, Michigan, and Wisconsin. These claims were to a greater or less extent conflicting. In some cases several States claimed authority over the same area, while the boundary lines were in most cases very ill-defined.

The ownership of these western lands by individual States was opposed by those States which did not share in their possession, mainly on the ground that the resources of the General Government, to which all contributed, should not be taxed for the protection and development of this region, while its advantages would inure to the benefit of but a favored few. On this ground several of the States refused to ratify the Constitution until this matter had been settled by the cession of these tracts to the General Government.

Moved by these arguments, as well as by the consideration of the conflicting character of the claims, which must inevitably lead to trouble among the States, Congress passed, on October 30, 1779, the following act:

> Whereas the appropriation of the vacant lands by the several States during the present war will, in the opinion of Congress, be attended with great mischiefs: Therefore,
>
> *Resolved*, That it be earnestly recommended to the State of Virginia to reconsider their late act of assembly for opening their land office; and that it be recommended to the said State, and all other States similarly circumstanced, to forbear settling or issuing warrants for unappropriated lands, or granting the same during the continuance of the present war.

This resolution was transmitted to the different States. The first to respond to it by the transfer of her territory to the General Government was New York, whose example was followed by the other States.

These cessions were made on the dates given below:

New York, March 1, 1781.

Virginia, March 1, 1784.

Massachusetts, April 19, 1785

Connecticut, September 13, 1786.

The Connecticut act of cession reserved an area in the northeastern part of Ohio, known as the Western Reserve. On May 30, 1800, Connecticut gave to the United States jurisdiction over this area, but without giving up its property rights in it.

South Carolina, August 9, 1787.

North Carolina, February 25, 1790.

Georgia, April 24, 1802.

The following paragraph from the deed of cession by New York defines the limits of its cession to the General Government:

Now, therefore, know ye, that we, the said James Duane, William Floid, and Alexander M'Dougall, by virtue of the power and authority, and in the execution of the trust reposed in us, as aforesaid, have judged it expedient to limit and restrict, and we do, by these presents, for and in behalf of the said State of New York, limit and restrict the boundaries of the said State in the western parts thereof, with respect to the jurisdiction, as well as the right or pre-emption of soil, by the lines and in the form following, that is to say: a line from the northeast corner of the State of Pennsylvania, along the north bounds thereof to its northwest corner, continued due west until it shall be intersected by a meridian line to be drawn from the forty-fifth degree of north latitude, through the most westerly bent or inclination of Lake Ontario; thence by the said meridian line to the forty-fifth degree of north latitude; and thence by the said forty-fifth degree of north latitude; but if, on experiment, the above-described meridian line shall not comprehend twenty miles due west from the most westerly bent or inclination of the river or strait of Niagara, then we do, by these presents, in the name of the people, and for and on behalf of the State of New York, and by virtue of the authority aforesaid, limit and restrict the boundaries of the said State in the western parts thereof, with respect to jurisdiction, as well as the right of pre-emption of soil, by the lines and in the manner following, that is to say: a line from the northeast corner of the State of Pennsylvania, along the north bounds thereof, to its northwest corner, continued due west until it shall be intersected by a meridian line, to be drawn from the forty-fifth degree of north latitude, through a point twenty miles due west from the most westerly bent or inclination of the river or strait Niagara; thence by the said meridian line to the forty-fifth degree of north latitude, and thence by the said forty-fifth degree of north latitude.

The deed of cession by Virginia gives no limits, further than to specify that the lands transferred include only those lying northwest of the river Ohio.

The following paragraph from the deed of cession by Massachusetts gives the limits of the area ceded:

* * * We do by these presents assign, transfer, quitclaim, cede, and convey to the United States of America, for their benefit, Massachusetts inclusive, all right, title, and estate of and in, as well the soil as the jurisdiction, which the said Com-

monwealth hath to the territory or tract of country within the limits of Massachusetts charter situate and lying west of the following line, that is to say, a meridian line to be drawn from the forty-fifth degree of north latitude through the westerly bent or inclination of Lake Ontario, thence by the said meridian line to the most southerly side line of the territory contained in the Massachusetts charter; but if on experiment the above-described meridian line shall not comprehend twenty miles due west from the most westerly bent or inclination of the river or strait of Niagara, then we do by these presents, by virtue of the power and authority aforesaid, in the name and on behalf of the said Commonwealth of Massachusetts, transfer, quitclaim, cede, and convey to the United States of America, for their benefit, Massachusetts inclusive, all right, title, and estate of and in as well the soil as the jurisdiction, which the said Commonwealth hath to the territory or tract of country within the limits of the Massachusetts charter, situate and lying west of the following line, that is to say, a meridian line to be drawn from the forty-fifth degree of north latitude through a point twenty miles due west from the most westerly bent or inclination of the river or strait of Niagara; thence by the said meridian line to the most southerly side line of the territory contained in the Massachusetts charter aforesaid.

The following clause from the act of the legislature of Connecticut, authorizing the cession, defines its limits:

*Be it enacted* * * * That the delegates of this State, or any two of them, who shall be attending the Congress of the United States, be, and they are hereby, directed, authorized, and fully empowered, in the name and behalf of this State, to make, execute, and deliver, under their hands and seals, an ample deed of release and cession of all the right, title, interest, jurisdiction, and claim of the State of Connecticut to certain western lands, beginning at the completion of the forty-first degree of north latitude, one hundred and twenty miles west of the western boundary line of the Commonwealth of Pennsylvania, as now claimed by said Commonwealth, and from thence by a line drawn north, parallel to and one hundred and twenty miles west of the said west line of Pennsylvania, and to continue north until it comes to forty-two degrees and two minutes north latitude. Whereby all the right, title, interest, jurisdiction, and claim of the State of Connecticut to the lands lying west of said line to be drawn as aforementioned, one hundred and twenty miles west of the western boundary line of the Commonwealth of Pennsylvania, as now claimed by said Commonwealth, shall be included, released, and ceded to the United States in Congress assembled, for the common use and benefit of the said States, Connecticut inclusive.

The cession of South Carolina was described as follows:

* * * All the territory or tract of country included within the river Mississippi and a line beginning at that part of the said river which is intersected by the southern boundary line of the State of North Carolina, and continuing along the said boundary line until it intersects the ridge or chain of mountains which divides the eastern from the western waters, then to be continued along the top of said ridge of mountains until it intersects a line to be drawn due west from the head of the southern branch of Tugaloo River to the said mountains; from thence to run a due west course to the river Mississippi.

The State of North Carolina ceded—

The lands situated within the chartered limits of the State, west of a line beginning on the extreme height of Stone Mountain, at the place where the Virginia line intersects it; running thence along the extreme height of the said mountain to the place where the Watauga River breaks through it; thence a direct course to the top of the Yellow Mountain where Bright's road crosses the same; thence along the ridge of the said mountain, between the waters of Doe River and the waters of Rock Creek, to the place where the road crosses the Iron Mountain; from thence along the extreme height of the

said mountain to where Nolechucky River runs through the same; thence to the top of the Bald Mountain; thence along the extreme height of the said mountain to the Painted Rock, on French Broad River; thence along the highest ridge of the said mountain to the place where it is called the Great Iron or Smoky Mountain; thence along the extreme height of the said mountain to the place where it is called the Unicoy or Unaka Mountain, between the Indian towns of Cowee and Old Chota; thence along the main ridge of the said mountain to the southern boundary of this State.

It will be noted that the above description of the eastern boundary of her ceded possessions agrees in general terms with the description of the western boundary of North Carolina, as given on page 96.

The articles of cession by Georgia describe the area ceded as follows:

The lands situated within the boundaries of the United States, south of the State of Tennessee and west of a line beginning on the west bank of the Chattahouchee River, where the same crosses the boundary line between the United States and Spain; thence running up the said river Chattahouchee and along the western bank thereof to the great bend thereof, next above the place where a certain creek or river, called Uchee (being the first considerable stream on the western side, above the Cussetas and Coweta towns), empties into the said Chattahouchee River; thence in a direct line to Nickajack, on the Tennessee River; thence crossing the last-mentioned river, and thence running up the said Tennessee River and along the western bank thereof to the southern boundary line of the State of Tennessee.

Of the area thus ceded to the General Government, the part lying north of the Ohio was afterwards erected into the "Territory Northwest of the River Ohio," and the balance, lying south of that river, was known as the "Territory South of the River Ohio."

## THE TERRITORY NORTHWEST OF THE RIVER OHIO.

This territory was bounded on the west by the Mississippi and the international boundary, on the north by the boundary line between the United States and the British Possessions, on the east by the Pennsylvania and New York state lines, and on the south by the Ohio River. It comprised an area of, approximately, 266,000 square miles. It was made up of claims of different States as follows:

1. Virginia uncontested claims, which consisted of all the territory west of Pennsylvania and north of the Ohio to the forty-first parallel of north latitude, besides her claim, by capture, as far as the northern limits of the land under the crown which had been subject to the jurisdiction of the provinces of Quebec and to Lakes Michigan and Huron.

2. The claim of Connecticut, which extended from the forty-first parallel northward to the parallel of 42° 2′, and from the west line of Pennsylvania to the Mississippi River.

3. The claim of Massachusetts, which extended from the north line of the Connecticut claim above noted to 43° 43′ 12″ north latitude, and from the eastern boundary of New York to the Mississippi.

4. The belt or zone lying north of the Massachusetts claim, extending thence to the Canada line and west to the Mississippi River, was claimed to have been obtained by the treaty of peace of Great Britain, September 3, 1783.

5. At the cession by the state of Virginia, both Massachusetts and New York claimed the Erie purchase of about 316 square miles, which was subsequently bought by Pennsylvania and added to that State.

From this territory were formed the following States: Ohio, Indiana, Illinois, Michigan, Wisconsin, that part of Minnesota east of the Mississippi River, and the northwest corner of Pennsylvania.

In 1787 a bill for its provisional division into not less than three nor more than five States was passed by Congress. In this bill the limits of the proposed States were defined, corresponding in their north and south lines to the boundaries of Ohio, Illinois, and Indiana, as at present constituted. The following gives the text of the clause defining these boundaries:

CONFEDERATE CONGRESS—AN ORDINANCE FOR THE GOVERNMENT OF THE TERRITORY OF THE UNITED STATES NORTHWEST OF THE RIVER OHIO.

* * * * * * *

ARTICLE 5. There shall be formed in the said territory not less than three nor more than five States; and the boundaries of the States, as soon as Virginia shall alter her act of cession and consent to the same, shall become fixed and established as follows, to wit: The western State, in said territory, shall be bounded by the Mississippi, the Ohio, and the Wabash River; a direct line drawn from the Wabash and Post Vincents, due north, to the territorial line between the United States and Canada; and by the said territorial line to the Lake of the Woods and Mississippi. The middle State shall be bounded by the said direct line, the Wabash from Post Vincents to the Ohio, by the Ohio, by a direct line drawn due north from the mouth of the Great Miami to the said territorial line, and by the said territorial line. The eastern State shall be bounded by the last-mentioned direct line, the Ohio, Pennsylvania, and the said territorial line: *Provided, however*, And it is further understood and declared, that the boundaries of these three States shall be subject so far to be altered, that, if Congress shall hereafter find it expedient, they shall have authority to form one or two States in that part of the said territory which lies north of an east and west line drawn through the southerly bend or extreme of Lake Michigan.

Passed July 13, 1787.

The provisions of this bill seem, however, never to have been carried out. A provisional government was instituted in 1788. By act of May 7, 1800, Congress divided this territory into two territorial governments, the divisional line being a meridian passing through the mouth of the Kentucky River and extending thence northward to the Canada border. The eastern portion became the "Territory Northwest of the River Ohio," and the western portion, Indiana Territory.

On November 29, 1802, the State of Ohio, comprising most of the former, was formed and admitted into the Union, while the remnant of it was added to Indiana Territory.

In 1805, all that portion of Indiana Territory lying north of a parallel

through the most southerly bend of Lake Michigan and east of a meridian drawn through the same point became the Territory of Michigan. The boundary between these territories was subsequently very much changed, as will appear in the sequel.

By act of February 3, 1809, Indiana Territory was again divided, and the Territory of Illinois was created from the part lying west of the Wabash River and a meridian running through the city of Vincennes, extending thence to the Canada line.

In 1816 Indiana, and in 1818 Illinois, were admitted to the Union as States, each with its boundaries as constituted at present. By the same act the Mississippi River was made the western boundary of the Territory of Michigan, thus making it include all the balance of the original Northwest Territory after the formation of the three States of Ohio, Indiana, and Illinois.

The act of 1834 added to Michigan Territory the land between the Missouri and White Earth Rivers on the west and the Mississippi River on the east.

Wisconsin Territory was formed in 1836 from the portion of Michigan Territory west of the present State of Michigan. On January 26, 1837, Michigan was admitted into the Union, with its present boundaries. In 1838 all that portion of Wisconsin Territory lying west of the Mississippi River and a line drawn due north from its source to the international boundary (that is, all that part which was originally comprised in the Louisiana purchase) was made the Territory of Iowa, and in 1848 Wisconsin was admitted as a State, with its boundaries as at present constituted.

This appears to leave the area which is now the northeastern part of Minnesota, lying east of the Mississippi River and a line drawn due north from its source, without any government until the formation of Minnesota Territory, in 1849.

## TERRITORY SOUTH OF THE RIVER OHIO.

The "Territory South of the River Ohio" was bounded on the north by the Ohio River, on the south by the thirty-first parallel of latitude, on the east by the States of Virginia, North Carolina, South Carolina, and Georgia, and on the west by the Mississippi River. The different cessions from the States which made up this region are as follows:

1. The region ceded by Virginia, which lay between the Ohio River on the North and, nominally, the parallel of 36° 30′ on the south, and between the Mississippi River and her present western boundary on the east, being the region which is now the State of Kentucky.

2. The area ceded by North Carolina, which extended from 36° 30′ north latitude southward to 35°, and from the western boundary line of

the present State to the Mississippi River. This is now the State of Tennessee.

3. The area ceded by South Carolina, which formed a narrow belt, 12 or 14 miles in width, lying south of the thirty-fifth parallel, and extending from her western boundary to the Mississippi River. It is doubtful whether under the terms of the original charters South Carolina possessed this strip, or whether it was not included in the possessions of Georgia.

4. The area ceded by Georgia, which comprised most of the region of the present States of Alabama and Mississippi, north of the thirty-first parallel.

Kentucky was admitted to the Union on June 1, 1792; Tennessee in 1796. In 1798 Congress organized the Territory of Mississippi, which was originally a small, rectangular area, bounded on the west by the Mississippi River, on the north by the parallel through the mouth of the Yazoo River; the boundary on the east was the river Chattahoochee, and on the south the thirty-first parallel of north latitude. This area was subsequently enlarged so as to include the whole of what is now Mississippi and Alabama, with the exception of a strip along the Gulf coast, which was at that time claimed by Spain. In 1817 the territory was divided, and the eastern portion was made into Alabama Territory. Subsequently the two Territories were admitted as States.

## LOUISIANA AND THE TERRITORY ACQUIRED FROM MEXICO.

The Louisiana purchase was effected in 1803. In 1804 it was divided into two parts, that portion which now comprises the State of Louisiana, with the exception of a small piece in the southeastern part, being organized as Orleans Territory, while the balance remained as the Louisiana Territory. The State of Louisiana, comprising the Territory of Orleans, was admitted to the Union in 1812, and in the same year it was enlarged by the addition of the portion lying between the Mississippi and Pearl Rivers, in the southeastern part. In the same year the name of Louisiana Territory was changed to Missouri Territory. In 1819 Arkansaw Territory, having very nearly the same limits as the present State of Arkansas, was created, and in 1836 it was admitted as a State.

In 1820 the State of Missouri was formed from another portion of Missouri Territory, and in 1836 the boundaries of this State were enlarged to their present limits. In 1834, as was stated above, that portion of this Territory lying north of the State of Missouri and east of the Missouri and White Earth Rivers was attached to the Territory of Michigan. In 1836 this portion was transferred from the Territory of Michigan to the Territory of Wisconsin. In 1838 it was transferred to

the Territory of Iowa. In 1845 the State of Iowa was created, and in 1846 its boundaries were enlarged. In 1849 the remainder of the Territory was transferred to Minnesota Territory. Minnesota was admitted as a State on May 11, 1858, with its present boundaries.

Meantime Texas had been admitted to the Union, and by the treaty of Guadalupe-Hidalgo and the Gadsden purchase, we had acquired from Mexico all the area west of the northern part of Texas and south of the forty-second parallel. Furthermore, our northern boundary had been established on the forty-ninth parallel to the Pacific Ocean.

Out of this great western region were carved the following Territories:

Oregon Territory, which was formed in 1848, and which extended from the parallel of 49° north latitude southward to latitude 42°, and from the Pacific Ocean east to the summit of the Rocky Mountains.

California, which was admitted as a State in 1849, with the same limits which it possesses at present.

Utah Territory, which was formed in 1850, and which extended from the forty-second parallel southward to the thirty-seventh, and from the California boundary line eastward to the Rocky Mountains.

New Mexico, which comprised all the country lying south of Utah to the boundary line of Texas and Mexico, and from the California boundary eastward to the boundary of Texas.

Nebraska Territory, which was formed from Missouri Territory in 1854. It comprised the country from the forty-ninth parallel down to the fortieth and from the Missouri and White Earth Rivers west to the summit of the Rocky Mountains.

Kansas Territory, formed by the same act as the last, comprised the country lying west of Missouri to the boundary of New Mexico and Utah, and from the south boundary of Nebraska to the thirty-seventh parallel.

Indian Territory then had its present limits.

Washington Territory was formed in 1853 from a part of Oregon, its southern boundary being the Columbia River and the parallel of 46° north latitude, and its east line being the summit of the Rocky Mountains.

Oregon was admitted as a State in 1857, with its boundaries as at present established. The portion cut off from Oregon Territory was placed under the territorial government of Washington Territory.

Dakota Territory was formed in 1861. As originally formed it comprised all that region between its present eastern and southern boundaries, while its western boundary was the summit of the Rocky Mountains.

The Territory of Nevada was organized from the western portion of the Territory of Utah in 1861. As originally constituted, its eastern line was the meridian of thirty-nine degrees of longitude west from Washington, and its southern boundary was the parallel of thirty-seven degrees of latitude. It was admitted as a State in 1864, its eastern

boundary being made the thirty-eighth degree of longitude (approximately the one hundred and fifteenth degree west from Greenwich), while its southern boundary remained the same. In 1866, by act of Congress, the eastern boundary was moved one degree farther to the eastward, placing it upon the thirty-seventh degree of longitude west from Washington, and the triangular portion contained between the former southern boundary, the boundary of California, the Colorado River and the meridian of thirty-seven degrees of longitude was added, thus giving the State its present area and limits.

Colorado Territory was formed in 1861, with the limits of the present State. It was admitted as a State in 1876.

The Territory of Arizona was formed from New Mexico in 1863, being that portion of New Mexico lying west of the thirty-second meridian west of Washington.

In the same year Idaho was formed from parts of Dakota and Washington Territories. As originally constituted it included all the territory lying east of the present eastern limits of Oregon and Washington Territory to the twenty-seventh degree of longitude west of Washington, the latter meridian being its eastern boundary. Its southern boundary was the northern boundary of Colorado and Utah—that is, the forty-first and forty-second parallels of latitude.

From this Territory was detached, in 1864, the Territory of Montana, with its present limits, and in 1868 the Territory of Wyoming, these several changes reducing Idaho to its present dimensions.

## CHAPTER III.

## THE BOUNDARY LINES OF THE STATES AND TERRITORIES.

### MAINE.

The first charter having any relation to the territory comprising the present State of Maine is that granted by Henry IV of France to Pierre du Gast, Sieur de Monts, in 1603, known as the charter of Acadia, which embraced the whole of North America between the fortieth and forty-sixth degrees of north latitude. Under this, several expeditions were made, and in 1606 it was decided to make a permanent settlement at Port Royal, now Annapolis, Nova Scotia, and no further attempts were made under this charter to plant colonies within the limits of the present State of Maine. (*Vide* Charters and Constitutions, p. 771.)

By the first charter of Virginia (*vide* Virginia, p. ), granted by James I, in 1606, the lands along the coast of North America between

the thirty-fourth and forty-fifth degrees of north latitude were given to two companies, to one of which, the Plymouth Company, was assigned that part of North America including the coast of New England. The first colony in Maine was planted on the peninsula of Sabine, at the mouth of the Kennebec River, now Hunnewell's Point, on August 19, 1607, O. S., by George Popham.

James I in 1620 granted a charter to the Plymouth Company, in which may be found the following, viz:

Wee, therefore * * * do grant ordain and establish that all that Circuit, Continent, Precincts and Limitts in America lying and being in Breadth from Fourty Degrees of Northerly Latitude from the Equnoctial Line, to Fourty eight Degrees of the said Northerly Latitude and in length by all the Breadth aforesaid throughout the Maine Land from Sea to Sea—with all the Seas, Rivers, Islands, Creekes, Inletts, Ports and Havens within the Degrees, Precincts and Limitts of the said Latitude and Longitude shall be the Limitts, and Bounds, and Precincts of the second collony—and to the end that the said Territoryes may hereafter be more particularly and certainly known and distinguished, our Will and Pleasure is, that the same shall from henceforth be nominated, termed and called by the name of New England in America.

Under this grant, given in 1621, the Earl of Stirling claimed that he was entitled to land on the coast of Maine which was afterwards granted to the Plymouth Company, and by direction of James I that company issued a patent to William Alexander, Earl of Stirling,

For a tract of the main land of New England, beginning at Saint Croix and from thence extending along the sea-coast to Pemquid and the river Kennebeck. (*Vide* Charters and Constitutions, p. 774.)

The heirs of the Earl of Stirling sold this tract to the Duke of York in 1663. (*Vide* Zell's Encyclopædia.)

In 1622 Capt. John Mason and Sir Ferdinando Gorges obtained from the council of Plymouth a grant of the lands lying between the Merrimac and Kennebec Rivers, and extending back to the river and lakes of Canada. This tract was called Laconia, and it included New Hampshire and all the western part of Maine. (*Vide* Whiton's New Hampshire.)

Mason and Gorges, in 1629, by mutual consent divided their territory into two by the river Piscataqua. That part on the east of this river was relinquished to Gorges, who called it Maine. (*Vide* Whiton's New Hampshire.)

The charter of the Plymouth Company was surrendered to the King in the year 1635. (*Vide* Plymouth Colony Laws, p. 333 *et supra.*)

King Charles I, in the year 1639, granted a charter to Sir Ferdinando Gorges, which virtually confirmed the patent given to him by the Plymouth Company in 1622.

The following extract from that charter defines the boundaries:

All that Parte Purparte and Porcon of the Mayne Lande of New England aforesaid beginning att the entrance of Piscataway Harbor and soe to passe upp the same into the River of Newichewanocke and through the same unto the furthest heade thereof and from thence Northwestwards till one hundred and twenty miles bee finished and from

Piscataway Harbor mouth aforesaid Northeastwards along the Sea Coasts to Sagadahocke and up the River thereof to Kynybequy River and through the same into the heade thereof and into the Lande Northwestwards untill one hundred and twenty myles bee ended being accompted from the mouth of Sagadahocke and from the period of one hundred and twenty myles aforesaid to crosse over Lande to the one hundred and twenty myles end formerly reckoned upp into the Lande from Piscataway Harbor through Newichewanocke River and also the Northe halfe of the Isles of Shoales togeather with the Isles of Capawock and Nawtican neere Cape Cod as alsoe all the Islands and Ilettes lyeinge within five leagues of the Mayne all alonge the aforesaide coasts betweene the aforesaid River of Pascataway and Sagadahocke with all the Creeks Havens and Harbors thereunto belonginge and the Revercon and Revercons Remaynder and Remaynders of all and singular the said Landes Rivers and Premisses. All which said Part Purpart or Porcon of the Mayne Lande and all and every the Premisses herein before named Wee Doe for us our heires and successors create and incorporate into One Province or Countie, and Wee Doe name ordeyne and appoynt that the porcon of the Mayne Lande and Premises aforesaid shall forever herefter bee called and named The Province or Countie of Mayne.

In 1664 Charles II granted to the Duke of York, who, the year before, had purchased the territory, which had been awarded to the Earl of Stirling in the division of the country to his heirs, a portion of the present State of Maine, and also certain islands on the coast, and a large territory west of the Connecticut River. (For the boundaries *vide* New York, p. 71 *et seq.*)

In 1674 Charles II made a new grant to the Duke of York, in substantially the same terms as that of 1664, including as before a portion of Maine. (*Vide* New York, p. 72.)

In the year 1677, Ferdinando Gorges, a grandson of Sir Ferdinando Gorges sold and gave a deed of the province of Maine to John Ushur, a merchant, of Boston, for £1,250. In the same year, Ushur gave a deed of the same territory to the governor and company of Massachusetts Bay, who had received a grant from the council of Plymouth in 1628, confirmed by the King in 1629. (*Vide* C. & C., p. 774.)

In 1686 Pemaquid and its dependencies, forming Cornwall County, under the jurisdiction of New York, were annexed to the New England government by a royal order, dated September 19, 1686. (*Vide* Maine Historical Society Collection, vol. 5.)

The charter of Massachusetts Bay of 1629 having been canceled in 1684, in 1691 William and Mary granted a new one, incorporating the provinces of Maine and Acadia, or Nova Scotia, with the colonies of Massachusetts Bay and of Plymouth, into one royal province by the name of the Royal Province of Massachusetts Bay. (*Vide* Mass., p. 48.)

The right of government thus acquired over the district of Maine was exercised by Massachusetts until 1819 when measures were taken to admit Maine as an independent State.

By the treaty of Paris in 1763 the King of France relinquished all claim to that portion of North America which includes the present State of Maine.

The northern and eastern boundaries were settled by the United States and Great Britain. (See p. 9, *et seq*).

The western boundary was for a long time a source of contention between Maine and New Hampshire.

New Hampshire having been made a province in 1679, controversies arose concerning the divisional line.

In 1731 commissioners from New Hampshire and from Massachusetts having been appointed, met, but were unable to agree. New Hampshire appealed to the King, and the King ordered that a settlement should be made by commissioners from the neighboring provinces. The board met at Hampton in 1737. The commissioners fixed on—substantially—the present boundary, wording their report as follows:

Beginning at the entrance of Pascataqua Harbor, and so to pass up the same to the River Newhichawack, and thro' the same into the furthest head thereof, and thence run north 2 degrees west till 120 miles were finished, from the mouth of Pascataqua Harbor, or until it meet with His Majesty's other Governments. (See N. H. Historical Coll., Vol. II.)

This was confirmed by the King, August 5, 1740.

In 1820 Maine was admitted, as an independent State.

Difficulties having arisen about the boundary between Maine and New Hampshire, commissioners were appointed in 1827 from each State to determine the same.

In 1829 the commissioners' report was adopted by each State, and the line then settled upon is as follows, using the language of the commissioners' report, viz:

The report of the commissioners appointed by His Majesty's order in Council of February 22nd, 1735, and confirmed by his order of the 5th of August, 1740, having established—

"That the dividing line shall pass up through the mouth of Piscataqua Harbor, and up the middle of the river of Newichwannock, part of which is now called the Salmons Falls, and through the middle of the same to the farthest head thereof, &c.," and "that the dividing line shall part the Isle of *Sholes*, and run through the middle of the harbor, between the islands to the sea on the southerly side, &c." We have not deemed it necessary to commence our survey until we arrived north, at the head of Salmon Falls River, which was determined by Bryant, at his survey in 1740, to be at the outlet of East pond, between the towns of Wakefield and Shapleigh. From that point we have surveyed and marked the line as follows, viz:

We commenced at the Bryant Rock, known as such by tradition, which is a rock in the middle of Salmon Falls River, at the outlet of East pond, about six feet in length, three feet in breadth, three feet in depth, and two feet under the surface of the water, as the dam was at the time of the survey, to wit, October 1, 1827; said stone bears south, seventy-one degrees west, three rods and eight links from a large rock on the eastern bank, marked "1827," and bears also from a rock near the mill-dam (marked "H") north, nineteen degrees and thirty minutes west, and distant twelve rods and twenty-one links. At this point the variation of the needle was ascertained to be *nine degrees* west.

From the above stone the line is north seven degrees and forty-one minutes east, one hundred and seventy-eight rods to East pond, and crossing the pond three hundred and eleven rods in width to a stone monument which we erected up on the bank, about three and an half feet high above the surface of the ground, marked N on the

west side and M on the east side, which description applies to all the stone monuments hereinafter mentioned unless they are otherwise particularly described; thence the same course, two hundred and twenty-five rods, to Fox Ridge, and to a stone monument which is placed upon the north side of the road that leads from Wakefield to Shapleigh; thence two hundred rods to Balch's pond; across the pond, one hundred and three and half rods; across a peninsula, thirty-six rods; across a cove, fifty-one rods and seventeen links; across a second peninsula, forty-eight rods; across a second cove, twenty-seven rods, ten links.

Thence three hundred and seventy rods, to the road leading from Newfield to Wakefield and a stone monument, erected on the north side of the same, near Campernell's house; thence north six degrees and ten minutes east, five hundred and ninety rods, to the line of Parsonfield, to a stone monument with additional mark "1828."

At this point the variation of the needle was found to be nine degrees fifteen minutes west. Thence same course five hundred and eleven rods, crossing the end of Province pond to a stone monument on the Parsonfield road, near the house of James Andrews, also with additional mark "1828"; thence north eight degrees and thirty-eight minutes east, two hundred and eight rods, to the old corner-stone of Effingham, about two feet above the ground, and not marked; thence north eight degrees fifty-five minutes east, two hundred and seventy-seven rods, to a large round stone about three feet diameter and two feet high, marked N and M, by the road upon Towles hill; thence north seven degrees fifty-five minutes east, six hundred and thirty-one rods to a stone monument, on the road leading from Parsonfield to Effingham. At this point the variation of the needle was found to be 9 degrees thirty minutes west. Thence north five degrees two minutes east, seven hundred thirty-four to a pine stump, upon a small island in Ossipee River at the foot of the falls; thence north ten degrees east, thirty rods, to a stone monument, on the north side of the new road from Porter to Effingham; thence the same course, five hundred fifty-eight rods, to the top of Bald Mountain; thence same course, three hundred sixteen rods, to the top of Bickford Mountain; thence same course one hundred and ninety-three rods, to a stone monument, on the north side of the road, leading from Porter to Eaton.

At this point the variation of the needle was found to be nine degrees forty-five minutes west; thence north eight degrees five minutes east, seven hundred and forty-four rods, to Cragged Mountain; thence same course, sixty-seven rods, to the corner of Eaton; thence same course, seven hundred eighty-seven and an half rods, to the corner of Conway; thence same course, six hundred ten and an half rods, to a stone monument, on the south side of the road, leading from Brownfield to Conway Center; thence north eight degrees east, eight hundred seventy-one rods, to a stone monument on the south side of the road leading from Fryeburg Village to Conway. At this point the variation of the needle was found to be ten degrees west; thence same course, four rods, to a stone monument on the north side of the same road; thence north eight degrees fifteen minutes east, one hundred two rods, to Saco River; thence same course, eighteen rods, across said river; thence same course, six hundred forty-four rods, to a stone monument on the road leading to Fryeburg Village, on the north side of the river.

This monument is marked as before described, and is about eight feet high above the ground; thence same course, one hundred forty-two rods, to Ballard's Mill Pond; thence same course, sixty-one rods, six links, across said pond; thence same course, three hundred forty-four rods, to a stone monument on the east side of Chatham road; thence same course, six hundred ninety rods, to Kimball's Pond; thence same course, one hundred sixty-six rods, across said pond; thence same course, sixty rods, to a stone monument on the meadow.[1] Thence same course, nine hundred forty rods, to the corner of Bradley and Eastman's grant; thence same course, six hundred and ninety rods, to a stone monument on the east side of the Cold River road. This stone is marked as

[1] From this point the line was resurveyed in 1858, *vide* p. 38.

before described, but is not more than two feet above the ground. Thence same course, one thousand five hundred forty rods, to the corner of Warner and Gilman's location, a pile of stones. At this point the variation of the needle was found to be ten degrees twenty-three minutes west; thence same course, four hundred and fifty rods, to top of Mount Royce; thence same course, eight hundred ninety-eight rods, to Wild River; thence same course, eight rods, across said river; thence same course, seven hundred sixty-five rods, to a stone monument on the north side of the road leading from Lancaster to Bethel; thence same course, one hundred rods, to Androscoggin River; thence same course, eighteen rods, across said river; thence north eight degrees ten minutes east, four thousand one hundred sixty-two rods, across ten streams, to Chickwalnepg River; thence same course, two thousand five hundred rods, to a stone monument on the north side of the road leading from Errol to Andover. This stone is marked "N. H." and "M.," thence same course two hundred ten rods to Cambridge River, thence same course eight rods across said river, thence same course five hundred sixty-seven rods to Umbagog Lake, thence same course thirty-four rods across a cove of the same, thence same course ten rods across a peninsula of the same, thence same course two hundred twenty-five rods across a bay of said lake, thence same course two hundred six rods across a peninsula of the same, thence same course one thousand one hundred sixty-five rods across the north bay of said lake to a cedar post marked "N." "M.," thence north eight degrees east seven hundred fourteen rods to Pond brook; thence same course two hundred twenty-five rods to a stone monument on the south side of the Margallaway River, thence same course ten rods across said river, thence same course one hundred sixty-two rods to a spruce, corner of the college grant, thence same course two hundred sixty-four rods to Margallaway River a second time. At this point the variation of the needle was found to be eleven degrees forty-five minutes west; thence same course ten rods across said river, thence same course two hundred and ninety rods to same river a third time, thence same course ten rods across said river to a monument made with three stones on the north side of said river, about two feet high and not marked, thence same course four hundred forty-four rods to corner of township number five, in second range, in Maine, thence same course one thousand eight hundred six rods to the north corner of the same township, thence same course four hundred and sixty rods to a branch of Little Diamond River, thence same course three hundred fifty rods to another branch of the same, thence same course two thousand one hundred twenty rods to a branch of the Margallaway River, thence same course three hundred thirty-two rods to another branch of the same, thence same course four hundred rods to a steep mountain called Prospect Hill, thence same course nine hundred and twenty rods to Mount Carmel, sometimes called Sunday Mountain, thence same course four hundred rods to a perpendicular precipice, thence same course five hundred and forty rods to a branch of Margalloway River, thence same course two hundred and sixty rods to a branch of the same, thence same course three hundred forty-six rods to a second steep precipice, thence same course one hundred eighty-six rods to a branch of Margallaway River, thence same course two hundred forty-two rods to another branch of same river, thence same course seventy-eight rods to a beaver pond, thence same course one hundred twenty-six rods to a yellow birch tree on the highlands which divide the waters that run south from those that run into the St. Lawrence, being the northern extremity of the line and one hundred and twelve miles two hundred and thirty-three rods from the head of Salmon Falls River.

Found said tree marked on the east side "M. E. 1789," and on the west "N. H. N. E.;" also "M. 54." To these marks we added "N. H.," "N. E.," and "M. E.," "1828," "E. H.," "A. M. M.," "1828," and stones were piled round the same and marked.

The whole course of the line from the Androscoggin River was re-marked by spotting the old marked trees and crossing the spots and marking others in the course. And the line as above survey and described we agree to be the true boundary line of

said States. And the above-described marks and monuments we establish to designate the same, and that the said line hereafter remain the boundary line between the States, unless the legislature of either State shall, at the first session after the execution of this agreement, disapprove of the same.

WILLIAM KING,
RUFUS McINTIRE,
*Commissioners of Maine.*
ICHABOD BARTLETT,
JOHN W. WEEKS,
*Commissioners of New Hampshire.*

NOVEMBER 13, 1828.

The legislature of Maine approved of the commissioners' report February 28, 1829, and requested the governor to issue his proclamation accordingly.

The same action was taken by the legislature of New Hampshire, July 1, 1829.

(For Report of Commissioners, see Laws of Maine, 1828–'9, under head of Resolves of the Ninth Legislature of the State of Maine, pages 39–43.)

Between 1828 and 1858, considerable portions of the amost unbroken forests through which the line of 1827–'28 was marked were cleared. Extensive forest fires often swept large tracts of this territory, and, as a consequence, the marks of the 1827–'28 survey for a distance of nearly eighty miles—which by that survey was mainly fixed by blazed trees, —only *seven* stone posts having been set in this distance—were obliterated, so that there remained scarcely a vestige of the original line. The lands having become valuable, and litigation in many cases being imminent, the legislatures of the two States in 1858 provided by enactment for another survey from Fryeburg to the Canada line—which was made the same year. The line as then surveyed is as follows, viz:

Commencing at an iron post[2] situated on the line run in accordance with the "Treaty of Washington, of August 9, 1842," as the boundary between the United States and the province of Canada, at the corners of the States of Maine and New Hampshire. On the south face of said post are the words "Albert Smith, U. S. Comssr."; on the north face, "Lt. Col. I. B. B. Eastcourt, H. B. M. Comssr."; on the west face, "Boundary, Aug. 9, 1842"; on the east face, "Treaty of Washington." To the marks are added on the southern half of the west face, "H. O. Kent." A large flat stone was placed on the southern face of the monument and marked "1858—N. H., Me.," on either side of a line cut in said stone bearing the direction of the State's line, viz, south, 8 degrees west.

From this point the line is south 8 degrees west, 17 rods, 7 links to a large yellow birch stub, the northern terminus of the former survey; thence 126 rods to a beaver pond; thence 73 rods to the northwesterly branch of the Margallaway, known as Kent River; thence 242 rods to another branch of the Margallaway; thence 186 rods to a certain steep precipice perpendicular on its southern face; thence 346 rods to a branch of the Margallaway River; thence 260 rods to another branch of the same; thence 540 rods to a precipice, the southern side of Mount Abbott; thence 400 rods to the summit

[2] The position of this post is given in Hitchcock's Geological Survey of New Hampshire, as follows, viz, latitude, 45° 18′ 23″.33; longitude, 71° 5′ 40″.5.

of Mount Carmel; thence 920 rods, and across four streams, to the summit of Prospect Hill.

On this distance we marked a yellow birch tree "H. O. Kent, September 20, 1858," and the names of the remainder of the party; thence 400 rods to another branch of the Margallaway; thence 332 rods to the Little Margallaway River; thence 2,120 rods across Bosebuck Mountain to a branch of said river. On this distance at the northwest corner of township No. 5, range 3, in Maine, we marked a white birch tree, "N. H. M.," and on its north and south sides, "IV, III." Thirty rods from the summit of Bosebuck Mountain, and on its northern slope, we erected a stone monument marked "N. M."; thence 330 rods to the Little Diamond River or Abbott Brook; thence 460 rods to the northwest corner of township No. 5, range 2, in Maine. On this distance we found an ancient yellow birch tree marked "1789-35, M." To these marks we added "1858"; thence 1,806 rods to the southwest corner of the same township. On this distance, at the northeast corner of Dartmouth College, second grant in N. H., we marked a large yellow birch tree "Me., J. M. W., 1858; N. H., H. O. K."; thence, and across an open bog, 444 rods to the north bank of the Margallaway River, to a white maple tree marked "N. H. M."; thence 10 rods across said river to a large pine tree marked "M." "N. H."; thence and across a second open bog 290 rods to the same river and to a large elm stub; thence 10 rods across said river; thence 264 rods to a spruce post marked "M." "N. H.", "W. L.", "D. C.", being the southeast corner of Dartmouth College, second grant; thence 162 rods to the Margallaway River; thence 10 rods across said river to a stone monument on its southerly side, standing about 3 feet above the ground and marked "M." "N. H."; thence to the original line tree nearest to the clearing of the home farm of Z. F. Durkee, esq. *The course of the line the entire distance from the iron post at the national boundary to this point bears south eight degrees west;* thence across said clearing, the old line marks being gone, south 11 degrees and 30 minutes west, 168 rods, to the old crossed trees in the woods south of Pond Brook; thence from Pond Brook south eight degrees west, 714 rods to the north bog of Umbagog Lake and to a cedar tree marked "M." "N." To this we added "1858."

On this distance near the corner of Errol and Wentworth's location, which is a cedar post in a pile of stones, we marked a maple tree "M. 1858," "N. H. 1858"; thence south ten degrees and thirty minutes west 1,165 rods, across the north bay of said lake to the old marked trees on the southern shore; thence south eight degrees west 206 rods across the peninsula to a cedar tree marked "M." "N. H." A large stone, also, on the lake shore was marked "M," "N. H."; thence same course 225 rods, across a bay of said lake; thence same course 10 rods, across a peninsula; thence same course 34 rods across a cove; thence same course 567 rods to Cambridge River; thence same course 8 rods, across said river to a white maple stub; thence same course 210 rods to a stone monument on the north side of the road leading from Andover, Me., to Colebrook, N. H.; thence same course to the north edge of the burnt land in Grafton and Success; thence south 11 degrees west across ten streams and the Chickwalmpy River, or Silver Stream, to the old line trees bearing the crosses, easterly of the south end of Success Pond; thence on the same course south 10 degrees west following the old mark to an ash tree bearing the original cross, standing a few rods north of the house of the late Daniel Ingalls, in Shelburne; thence south 11 degrees west to a stone monument, by the road on the north side of the Androscoggin River, and to the north bank of said river, the whole distance from the stone monument near Umbagog Lake to the north bank of the Androscoggin River, being 6,662 rods; thence south 11 degrees west 18 rods across said river; thence same course 100 rods, crossing the track of the Grand Trunk Railway to a stone monument on the north side of the road leading from Lancaster, N. H., to Bethel, Me; thence same course, 765 rods to a hemlock tree on the south bank of Wild River; thence south 66 degrees 30 minutes west 34 rods on an offset of the old survey along said south bank to the old line trees; thence following the old line trees

south 11 degrees west, passing the southeast corner of Shelburne, 898 rods to the top of Mount Royce, the whole distance being 1,881 rods. One mile north of the summit of Mount Royce we marked a beech tree "N. H." "M.," 1858; thence to a large stone marked "N. H." "Me."; thence south 10 degrees 15 minutes west to a stone monument on the east side of the Cold River road. On this distance at the foot of the first precipice on the northern face of Mount Royce a white-birch tree was marked "1858." Further on and east of a bare ledge a white-birch tree was marked "1858," and near it, on the line, a pile of stones was erected. At the first clearing, near the north end of a stone fence, a large stone was marked "M." "N. H."; thence along a stone fence and across a road through a piece of new growth and again crossing the road; then following another stone fence on the east side of the road, passing through a field and by the end of another stone fence; then crossing a road near the west end of a bridge over Cold River; then following the valley of that stream and crossing it six times; then crossing another road, where we placed a stone monument; then through a field, striking an old stump and pile of stones, shown as the old line and passing between a house and barn, and through the western edge of a grove of trees to the stone monument near the house of Mr. Eastman, the whole distance being 1,190 rods; thence 1,630 rods to a stone monument standing in the meadow 60 rods north of the north shore of Kimball's pond, in Fryeburg.

But as the towns of Fryeburg and Stowe have erected no durable monument on the State's line at their respective corners, we deemed it advisable, under our instructions, to proceed so far south as at least to pass the said corner and to complete the work at some well-defined monument of the old survey.

This course bore from the monument to and across an open bay south 12 degrees west; thence on the old trees south 9 degrees west 100 rods; thence on the old line south 10 degrees 30 minutes west to a stone monument erected by us near the house of Jonnet Clay, in Chatham, and on the north side of the road leading from Stowe to Chatham Corners; said monument is marked "M." "N. H." 1858; thence on the old line south 11 degrees west to the road leading from North Fryeburg to Chatham, at which point we placed a stone monument; thence south 11 degrees west to the northwest corner of Fryeburg, being a stake in a pile of stones in a piece of low ground, southerly of the house of Captain Bryant, and to the old monument, 60 rods north of Kimball's pond. On the bank north of said corner, on the south side of the road, and near Captain Bryant's house, we placed a stone monument marked "M." "N. H. 1858."

The different courses laid down in the foregoing report are the bearings of the compass in 1858 when placed on the line established in 1828. (See Legislative Journal of New Hampshire, 1859, pages 764–767.)

In 1874 the line between Maine and New Hampshire was resurveyed and marked. (*Vide* Hitchcock's Geology of New Hampshire, Vol. I, p. 173.)

## NEW HAMPSHIRE.

The first charter of Virginia, granted in 1606, included the territory of the present State of New Hampshire (*vide* p. 32), as did the charter of New England, granted in 1620 (*vide* p. 33), and the grant to Capt. John Mason and Sir Ferdinando Gorges of 1622 (*vide* p. 33).

The president and council of New England made a grant to Capt. John Mason in 1629 as follows, viz:

* * * * * * *

All that part of the main land in New England lying upon the sea coast, beginning from the middle part of Merrimack River, and from thence to proceed northwards along the sea-coast to Piscataqua River, and so forwards up within the said river and to the furthest head thereof, and from thence northwestwards until three score miles be finished from the first entrance of Piscataqua River and also from Merrimack through the said river and to the furthest head thereof, and so forward up into the lands westward until three score miles be finished, and from thence to cross overland to the three score miles, and accompted to Piscataqua River, together with all islands and islets within 5 leagues distance of the premises and abutting upon the same, or any part or parcel thereof, &c., * * * which said portions of lands * * * the said Capt. John Mason, with the consent of the president and council, intends to name *New Hampshire*. * * *

In 1635 the grant of 1629 was confirmed by a supplementary grant, of which the following is an extract, viz:

All that part of the Mayn Land of New England aforesaid, beginning from the middle part of Naumkeck River, and from thence to proceed eastwards along the Sea Coast to Cape Anne, and round about the same to Pischataway Harbour, and soe forwards up within the river Newgewanacke, and to the furthest head of the said River and from thence northwestwards till sixty miles bee finished, from the first entrance of Pischataway Harbor, and alsoe from Naumkecke through the River thereof up into the land west sixty miles, from which period to cross over land to the sixty miles end, accompted from Pischataway, through Newgewanacke River to the land northwest aforesaid; and alsoe all that the South Halfe of the Ysles of Sholes, all which lands, with the Consent of the Counsell, shall from henceforth be called New-hampshyre. And alsoe ten thousand acres more of land on the southeast part of Sagadihoc at the mouth or entrance thereof—from henceforth to bee called by the name of Massonia, &c. * * *

After the death of Capt. John Mason (in December, 1635), the affairs of the colony coming into bad condition, they sought the protection of Massachusetts in 1641 and enjoyed it till 1675, when Robert Mason, a grandson of John Mason, obtained a royal decree, under which, in 1680, a colonial government was established. But no charter was given to the colony, and its government was only continued during the pleasure of the King. The following is an extract from the commission, or decree, issued by the King in 1680:

Province of New Hampshire, lying and extending from three miles northward of Merrimack River or any part thereof into ye Province of Maine.

In the year 1690 the province of New Hampshire was again taken under the jurisdiction of Massachusetts Bay, but was again separated in 1692.

[For a history of the boundary between New Hampshire and Maine, *vide* Maine, p. 35.]

The controversy already referred to arising between the provinces of New Hampshire and Massachusetts Bay not only involved the settlement of the boundary between New Hampshire and Maine, but also that between New Hampshire and Massachusetts, and, as before stated (*vide* Maine, p. 35), the commissioners appointed by the two provinces having been unable to agree, New Hampshire appealed to the King, who

ordered that the boundaries should be settled by a board of commissioners appointed from the neighboring colonies.

The board met at Hampton in 1737, and submitted a conditional decision to the King, who in 1740 declared in council as follows, viz:

That the northern boundary of the province of Massachusetts be a similar curve line pursuing the course of the Merrimac River, at three miles distance, on the north side thereof, beginning at the Atlantic Ocean and ending at a point due north of Pawtucket Falls, and a straight line drawn from thence, due west, till it meets with His Majesty's other Governments. (*Vide* Vermont State Papers, Slade, p. 9.)

New Hampshire claimed her southern boundary to be a line due west from a point on the sea three miles north of the mouth of Merrimac River. Massachusetts claimed all the territory three miles north of any part of Merrimac River. The King's decision gave to New Hampshire, a strip of territory more than fifty miles in length and of varying width, in excess of that which she claimed. This decree of the King was forwarded to Mr. Belcher, then governor of both the provinces of New Hampshire and Massachusetts Bay, with instructions to apply to the respective assemblies to unite in making the necessary provisions for running and marking the line conformable to the said decree, and if either assembly refused, the other was to proceed *ex parte*. Massachusetts Bay declined complying with this requisition. New Hampshire, therefore, proceeded alone to run and mark the line.

George Mitchel and Richard Hazen were appointed by Belcher to survey and mark the line. Pursuant to this authority, in the month of February, 1741, Mitchel ran and marked the line from the sea-coast about three miles north of the mouth of the Merrimac River to a point about three miles north of Pawtucket Falls, and Hazen, in the month of March following, ran and marked a line from the point, three miles north of Pawtucket Falls, across the Connecticut River, to the supposed boundary line of New York, on what he then supposed to be a due west course from the place of beginning. He was instructed by Governor Belcher to allow for a westerly variation of the needle of ten degrees. (*Vide* New Hampshire Journal H. R., 1826.)

The report of the surveyors has not been preserved, but the journal of Hazen has been found, and is published in the New England Historical and General Register, July, 1879.

Subsequent investigation has proved that this line was not run on a due west course, the allowance for the westerly variation of the needle being quite too large, throwing the line north of west.

This mistake seems to have been known previous to the Revolution. In 1774 calculations were made by George Sproule, founded upon actual surveys and accurate astronomical observations, from which he determined that Hazen's line was so far north of west as to lose to the State of New Hampshire quite a large tract of land. (*Vide* New Hampshire Journal H. R., 1826.)

In 1825 commissioners were appointed by the States of New Hamp-

shire and Massachusetts to ascertain, run, and mark the line between the two States, under the proceedings of which New Hampshire asserted her claim to a due west line, conformable to the decree of 1740, it being apparent by a survey made by the commissioners that the original line was north of west. This the Massachusetts commissioners refused to do, alleging that they were only empowered to ascertain and mark the original line.

On March 10, 1827, the legislature passed a resolution providing for the erection of durable monuments to preserve the boundary line between the States of Massachusetts and New Hampshire, as the same had been run and ascertained by the commissioners; and monuments were erected accordingly. (*Vide* Resolves of Massachusetts, 1827.)

In 1830–'8 a trigonometrical survey of the State of Massachusetts was made under the direction of Simeon Borden.

A table of the latitudes and longitudes of points on the north boundary of Massachusetts, taken from that survey, will be found under Massachusetts, p. 64, from which the true course of the Hazen line, as marked by the commissioners in 1827, may be readily discovered.

Under the decree of the King of 1740 the province of New Hampshire claimed jurisdiction as far west as the territory of Massachusetts and Connecticut extended, thus including the present State of Vermont. New York claimed all the country west of the Connecticut, under the charters of 1664 and 1674 to the Duke of York. A bitter controversy ensued. The following papers serve to throw some light on the matter:

*Letter from the Governor of New Hampshire to the Governor of New York.*

PORTSMOUTH, *November* 17, 1749.

* * * I think it my duty * * * to transmit to your excellency the description of New Hampshire as the King has determined it in the words of my commission. * * * In consequence of His Majesty's determination of the boundaries between New Hampshire and Massachusetts, a surveyor and proper chainmen were appointed to run the western line from 3 miles north of Pautucket Falls, and the surveyor upon oath has declared that it strikes Hudson's River about 80 poles north of where Mohawk's River comes into Hudson's River.

* * * * * * *

B. WENTWORTH.

(See State Papers of Vermont, Slade 1, page 10.)

The following is a description of the bounds of New Hampshire given to Governor Benning Wentworth, of province of New Hampshire, by George II, July 3, 1741:

George the Second, by the Grace of God, of Great Britain, France, and Ireland King, Defender of the Faith, &c.

*To our trusty and well-beloved Benning Wentworth, Esqr., greeting:*

Know you that we, reposing especial trust and confidence in the prudence, courage, and loyalty of you, the said Benning Wentworth, out of our especial grace, certain

knowledge, and meer motion, have thought fit to constitute and appoint, and by these presents do constitute and appoint you, the said Benning Wentworth, to be our governor and commander-in-chief of our province of New Hampshire, within our dominions of New England in America, bounded on the south side by a similar curve line pursuing the course of Merrimac River at three miles distance, on the north side thereof, beginning at the Atlantick Ocean and ending at a point due north of a place called Pautucket Falls, and by a straight line drawn from thence due west cross the said river 'till it meets with our other Governments. * * *

Given at Whitehall July the 3rd, in the 15th year of His Majesty's reign.

(See Documentary History of N. York, vol. 4, page 331.)

The question of the right of territory was submitted to the King, who in 1764 made the following decree:

ORDER IN COUNCIL FIXING THE BOUNDARY BETWEEN NEW YORK AND NEW HAMPSHIRE.

[L. S.] AT THE COURT AT ST. JAMES,
*The 20th day of July*, 1764.

Present: The King's Most Excellent Majesty; Lord Steward, Earl of Sandwich, Earl of Halifax, Earl of Powis, Earl of Hilsborough, Mr. Vice Chamberlain Gilbert Eliot, Esqr., James Oswald, Esqr., Earl of Harcourt.

Whereas there was this day read at the Board a report made by the right honorable the lords of the committee of council for plantation affairs, dated the 17th of this instant, upon considering a representation from the lords commissioners for trade and plantations, relative to the disputes that have some years subsisted between the provinces of New Hampshire and New York, concerning the boundary line between those provinces, His Majesty, taking the same into consideration, was pleased with the advice of his Privy Council to approve of what is therein proposed, and doth accordingly hereby order and declare the western banks of the river Connecticut, from where it enters the province of the Massachusetts Bay, as far north as the forty-fifth degree of northern latitude, to be the boundary line between the said two provinces of New Hampshire and New York. Whereof the respective governors and commanders in chief of His Majesty's said provinces of New Hampshire and New York for the time being, and all others whom it may concern, are to take notice of His Majesty's pleasure hereby signified and govern themselves accordingly.

WM. BLAIR.

(*Vide* Documentary History of New York, vol. 4, p. 355.)

Notwithstanding this decree of the King, controversy, attended with violence, was kept up for many years; but the line was finally accepted and now forms the boundary line between the States of New Hampshire and Vermont.

The northern boundary of New Hampshire was settled by the United States and Great Britain. (*Vide* p. 9 *et seq.*)

It is as follows, viz:

Commencing at the "Crown Monument," so called, at the intersection of the State of New Hampshire, Maine, and the Province of Quebec, in latitude 45° 18′ 23″.33, longitude 71° 5′ 40″.5, thence in an irregular line to Hall's Stream, thence down the same to the northeastern corner of Vermont, in latitude 45° 0′ 17″.58, longitude 71° 30′ 34″.5. (*Vide* Hitch. Geology of New Hampshire.)

## VERMONT.

The grants from King Henry, of France, of 1603, and King James, of England, of 1606, both included that territory which forms the present State of Vermont. It was also included in the charter of New England of 1620.

In the grants to the Duke of York, in 1664 and 1674, all the territory between the Connecticut and Delaware Rivers was included. New York, therefore, claimed jurisdiction of the territory now known as Vermont. Massachusetts, however, at an early period, having made claim to the tract west of the Connecticut River, now a portion of that State, by the interpretation of her charter, claimed the greater part of the same territory. By the terms of the charter of Massachusetts Bay, of 1629, that colony was granted all the lands—

Which lye and be within the space of Three English myles to the northward of the saide River called Monomack alias Merrymack, or to the norward of any and every Parte thereof.

Under this clause Massachusetts Bay claimed that her jurisdiction extended 3 miles north of the farthest part of the Merrimac River, which would embrace a large portion of New Hampshire and Vermont. New Hampshire contested this claim, and after several years' controversy was more than sustained by a decision of the King in 1740. New Hampshire in her turn claimed the territory of Vermont, on the ground that Massachusetts and Connecticut, having been allowed to extend their boundaries to within 20 miles of the Hudson River, her western boundary should go equally as far, and contended that the King's decree of 1740 left that fairly to be inferred; also, that the old charters of 1664 and 1674 were obsolete.

By a decree of the King, however, the territory west of the Connecticut River, from the 45th parallel of north latitude to the Massachusetts line, was declared to belong to the province of New York. (*Vide* New Hampshire, p. 44.)

As most of the settlers of Vermont were from New Hampshire, this decision of the King caused great dissatisfaction, and the Revolution found Vermont the scene of conflicting claims, and the theatre of violent acts, culminating, in some instances, in actual bloodshed.

On January 15, 1777, Vermont declared herself independent and laid claim to the territory west as far as the Hudson River, and from its source north to the international boundary, including a tract along the west shore of Lake Champlain. A part of New Hampshire, also, at one time, sought a union with Vermont.

In 1781 Massachusetts assented to her independence. She adjusted her differences with New Hampshire in 1782, but eight years more passed before New York consented to her admission into the Union.

In 1791 Vermont was admitted as an independent State, but was required to restrict her boundaries to their present extent.

The act of New York, of March 6, 1790, giving her consent to the admission of Vermont, defines her boundaries. (*Vide* Slade's Vermont, p. 507.)

The northern boundary was settled by the United States and Great Britain by the treaty of Washington, in 1842. (*Vide* p. 16.)

The eastern boundary is low-water mark on the west bank of the Connecticut River. (*Vide* New Hampshire, p. 44.)

The southern boundary was settled by the decree of 1740. (*Vide* New Hampshire, p. 42.)

The line between Vermont and New York was surveyed and marked by commissioners from the two States in 1814, and is as follows, viz:

Beginning at a red or black oak tree, the northwest corner of Massachusetts, and running north 82° 20′ west as the magnetic needle pointed in 1814, 50 chains, to a monument erected for the southwest corner of the State of Vermont, by Smith Thompson, Simon De Witt, and George Tibbitts, commissioners on the part of New York, and Joseph Beeman, jr., Henry Olin, and Joel Pratt second, commissioners on the part of the State of Vermont, which monument stands on the brow of a high hill, descending to the west, then northerly in a straight line to a point which is distant 10 chains, on a course, south 35 degrees west, from the most westerly corner of a lot of land distinguished in the records of the town of Pownal, in the State of Vermont, as the fifth division of the right of Gamaliel Wallace, and which, in the year 1814, was owned and occupied by Abraham Vosburgh; then north 35 degrees east to said corner and along the westerly bounds of said lot, 30 chains to a place on the westerly bank of Hasick River, where a hemlock tree heretofore stood, noticed in said records as the most northerly corner of said lot; then north 1 degree and 20 minutes west, 6 chains to a monument erected by the said commissioners, standing on the westerly side of Hasick River, on the north side of the highway leading out of Hasick into Pownal, and near the northwesterly corner of the bridge crossing said river; then north 27 degrees and 20 minutes east, 30 chains, through the bed of the said river, to a large roundish rock on the northeasterly bank thereof; then north 25 degrees west, 16 chains and 70 links; then north 9 degrees west, 18 chains and 60 links, to a white-oak tree, at the southwest corner of the land occupied in 1814 by Thomas Wilsey; then north 11 degrees east, 77 chains to the north side of a highway, where it is met by a fence dividing the possession of said Thomas Wilsey, jr., and Emery Hunt; then north 46 degrees east, 6 chains; then south 66 degrees east, 26 chains and 25 links; then north 9 degrees east, 27 chains and 50 links to a blue-slate stone, anciently set up for the southwest corner of Bennington; then north 7 degrees and 30 minutes east, 46 miles 43 chains and 50 links to a bunch of hornbeam saplings on the south bank of Poultney River, the northernmost of which was marked by said last-mentioned commissioners, and from which a large butternut tree bears north 70 degrees west, 30 links, a large hard maple tree, south 2 chains and 86 links, and a white ash tree on the north side of said river, north 77 degrees east.

Which said several lines from the monument erected for the southwest corner of the State of Vermont were established by said last-mentioned commissioners, and were run by them, as the magnetic needle pointed, in the year 1814, then down the said Poultney River, through the deepest channel thereof to East Bay; then through the middle of the deepest channel of East Bay and the waters thereof to where the same communicate with Lake Champlain; then through the deepest channel of Lake Champlain to the eastward of the islands called the Four Brothers, and the westward of the islands called the Grand Isle and Long Isle, or the Two Heroes, and to the west-

ward of the Isle La Motte to the line in the 45th degree of north latitude, established by treaty for the boundary line between the United States and the British Dominions. (See Revised Statutes of New York, Banks & Brothers, sixth edition, Vol. I, pp. 122–123.)

This line was changed in 1876 by a cession of a small territory from Vermont to New York, described as follows, viz:

All that portion of the town of Fairhaven, in the county of Rutland, and State of Vermont, lying westerly from the middle of the deepest channel of Poultney River as it now runs, and between the middle of the deepest channel of said river and the west line of the State of Vermont as at present established. (Ratified by Congress April 7, 1880.)

## MASSACHUSETTS.

The territory of Massachusetts was included in the first charter of Virginia, granted in 1606, (*Vide* Virginia p., 88) and in the charter of New England, granted in 1620, (*Vide* Maine p. 33.)

In 1628 the council of Plymouth made a grant to the governor and company of Massachusetts Bay in New England, which was confirmed by the King, and a charter was granted in 1629, of which the following are extracts:

* * * Nowe Knowe Yee, that Wee * * * have given and granted * * * all that Parte of Newe England in Amirica which lyes and extends betweene a great River there commonlie called Monomack River, alias Merrimack River, and a certen other River there, called Charles River, being in the Bottome of a certen Bay there, comonlie called Massachusetts alias Mattachusetts, alias Massatusetts Bay, and also all and singuler those Landes and Hereditament whatsoever, lying within the Space of Three Englishe Myles on the South Parte of the said River called Charles River, or of any or every Parte thereof. And also all and singuler the Landes and Hereditaments whatsoever, lying and being with the space of Three Englishe Miles to the southward of the southermost Parte of the said Baye, called Massachusetts, alias Mattachusetts, alias Massatusetts Bay—and also all those Lands and Hereditaments whatsoever, which lye and be within the space of Three English Myles to the Northward of the saide River, called Monomack, alias Merrymack, or to the Norward of any and every Parte thereof and all Landes and Hereditaments whatsoever, lyeing within the Lymitts aforesaide, North and South, in Latitude and Bredth, and in Length and Longitude, of and within all the Bredth aforesaide, throughout the Mayne Landes there from the Atlantick and Westerne Sea and Ocean on the East Parte, to the South Sea on the West Parte.

* * * Provided alwayes, That yf the said Landes * * * were at the tyme of the graunting of the saide former Letters patents, dated the Third Day of November, in the Eighteenth yeare of our said deare Fathers Raigne aforesaide, actuallie possessed or inhabited by any other Christian Prince of State, or were within the Boundes Lymitts or Territories of that Southern Colony, then before graunted by our saide late Father * * * That then this present Graunt shall not extend to any such partes or parcells thereof * * * but as to those partes or parcells * * * shal be vtterlie voyd, theis presents or any Thinge therein conteyned to the contrarie notwistanding * * *

The charter of New England was surrendered to the King in 1635. (*Vide* Plymouth Colony Laws, p. 333.)

The charter of 1629 was canceled by a judgment of the high court of chancery of England, June 18, 1684. (*Vide* C. & C., p. 942.)

In the year 1686, Pemaquid and its dependencies were annexed to the New England government. (*Vide* Maine, p. 34.)

In 1691 a new charter was granted to Massachusetts Bay, which included Plymouth Colony and the Provinces of Maine and Nova Scotia. The following are extracts from this charter:

* * * Wee * * * do will and ordeyne that the Territories and Collonyes Commonly called or Known by the names of the Collony of the Massachusetts Bay and Collony of New Plymouth the Province of Main the Territorie called Accadia or Nova Scotia and all that tract of Land lying betweene the said Territories of Nova Scotia and the said Province of Main be erected Vnited and Incorporated * * * into one reall Province by the Name of Our Province of the Massachusetts Bay in New England. * * *

All that parte of New England in America lying and extending from the greate River comonly called Monomack als Merrimack on the Northpart and from three Miles Northward of the said River to the Atlantick or Western Sea or Ocean on the South part And all the Lands and Hereditaments whatsoever lying within the limitts aforesaid and extending as farr as the Outermost Points or Promontories of Land called Cape Cod and Cape Mallabar North and South and in Latitude Breadth and in Length and Longitude of and within all the Breadth and Compass aforesaid throughout the Main Land there from the said Atlantick or Western Sea and Ocean on the East parte towards the South Sea or Westward as far as Our Collonyes of Rhode Island Connecticutt and the Narragansett Countrey all alsoe all that part or porcon of Main Land beginning at the Entrance of Pescataway Harbour and soe to pass vpp the same into the River Newickewannock and through the same into the furthest head thereof and from thence Northwestward till One Hundred and Twenty miles be furnished and from Piscataway Harbour mouth aforesid North-Eastward along the Sea Coast to Sagadehock and from the Period of One Hundred and Twenty Miles aforesaid to crosse over Land to the One Hundred and Twenty Miles before reckoned up into the Land from Piscataway Harbour through Newickawannock River and alsoe the North halfe of the Isles and Shoales togather with the Isles of Cappawock and Nantukett near Cape Cod aforesaid and alsoe [all] Lands and Hereditaments lying and being in the Countrey and Territory comonly called Accadia or Nova Scotia And all those Lands and Hereditaments lying and extending betweene the said Countrey or Territory of Nova Scotia and the said River of Sagadahock or any part thereof And all Lands Grounds Places Soiles Woods and Wood grounds Havens Ports Rivers Waters and other Hereditaments and premisses whatsoever, lying within the said bounds and limitts aforesaid and every part and parcell thereof and alsoe all Islands and Isletts lying within tenn Leagues directly opposite to the Main Land within the said bounds. * * *

(For an account of the settlement of the boundary between the District of Maine, formerly a part of Massachusetts, see Maine, p. 35.)

The present northern boundary of Massachusetts was settled in 1741. (For history, see New Hampshire, p. 43.)

The boundary line between Massachusetts and Rhode Island was for more than two hundred years a question of dispute, and was, in some respects, the most remarkable boundary case with which this country has had to do. Twice the case went to the Supreme Court of the United States, and in one of these suits Daniel Webster and Rufus Choate were employed as counsel for Massachusetts.

As early as 1642 the line between the two colonies was marked in part by Nathaniel Woodward and Solomon Saffrey, who set up on the plain of Wrentham a stake as the commencement of the line between Massachusetts Bay and Rhode Island. This stake was by them supposed to mark a point 3 miles south of the Charles River.

The report of these commissioners has not been found, but frequent reference is made to their survey in the record of the subsequent controversies and litigations.

In 1710–'11 commissioners appointed from Massachusetts and Rhode Island agreed upon the north line of Rhode Island. The action of the commissioners was approved by the legislatures of both colonies.

The agreement was as follows, viz:

That the stake set up by Nathaniel Woodward and Solomon Saffrey, skillful, approved artists, in the year of our Lord 1642, and since that often renewed in the latitude of 41° 55′, being 3 English miles distant southward from the southernmost part of the river called Charles River, agreeable to the letters patent for the Massachusetts Province, be accounted and allowed on both sides the commencement of the line between the Massachusetts and the colony of Rhode Island, from which said stake the dividing line shall run, so as it may (at Connecticut River) be 2¼ miles to the southward of a due west line, allowing the variation of the compass to be 9°; which said line shall forever, &c. (*Vide* Howard's Reports, S. C., Vol. 4, p. 631, *et seq.*)

In 1719 this line was run by commissioners appointed for the purpose. Subsequent investigation has shown that this line was run in a very irregular manner. (*Vide* R. I. Acts, May, 1867, page 6, *et seq.*)

The line between Massachusetts and the eastern part of Rhode Island was fixed by commissioners in 1741, from the decision of whom the colony of Rhode Island appealed to the King, who, in the year 1746, affirmed their decision by a royal decree.

The following is a record of the proceedings in council, together with the royal decree.

[Council Office. Council Register. Geo. II, No. 8, p. 204.]

AT THE COURT AT KENSINGTON
*the 29th day of July* 1742.

Present. The Kings Most Excellent Majesty, Archbp[d] of Canturbury, Earl of Pembroke, Lord President Earl of Winchelsea, Lord Privy Seal Earl of Grantham, Duke of Bolton, Earl of Cholmondelly, Duke of Rutland, Earl of Wilmington, Marq[s] of Tweedale, Earl of Bath, Visco[t] Lonsdale, Mr. Chancellor of the Exche[cr], Lord Delaware, Sr Charles Wager, Lord Bathurst, Sr. William Younge, Lord Monsore, Sr John Norris, Mr Speaker Thomas Winnington Esq., Mr. Vice Chamberlin, George Wade Esq.

Upon reading this day at the board the humble Petetion and appeale of the Governor and company of the English of Rhode Island and Providence Plantations in New England in America from several particular parts of the determination of the commissioners appointed by his Majesty to settle the Boundary's of the said colony Eastwards with the Province of Massachusetts Bay, and humbly praying that a day may be appointed for hearing said appeal, and that the particular parts of the said commissioners determination appealed from may be reversed, and such other deter-

mination made instead thereof as shall be agreeable to the true construction of the Boundarys contained in the Royal Charter under which the Petioners claim, it is ordered by his Majesty in Council that the said Petition and appeal (a copy whereof is hereunto annexed). Be and it is hereby referred to the Right Honorable the Lord of the committee of council for hearing appeals from the Plantations to hear the same, and report their opinion thereupon to his Majesty at the Board.

A true copy.

I. B. LENNARD.

Collated with the original entry in the Council Register, 18 Jan'y, 1845.

ROBT. LEMON.

[Council Office. Council Register. Geo. II, No. 8 p. 235.]

AT THE COURT OF KENSINGTON,
*the 15th day of Sept.* 1742.

Present, The Kings most Excellent Majesty Archbp of Canturbury, Lord Delmar Lord Chancellor, Mr Vice Chamberlin, Duke of Richmond, Mr. Chancellor of the Exchequer, Duke of Newcastle, Harry Pelham Esq. Earl of Winchelsea, Thomas Winnington Esq Earl of Wilmington George Wade Esq. Lord Cartaret.

Upon reading this day at the Board the humble Petition and appeale of His Majesty's Province of the Massachusetts Bay in New England from the determination of the commissioners appointed by His Majesty to settle the Boundary of the Colony of Rhode Island Eastwards, with the said province of Massachusetts Bay and humbly praying that a day may be appointed for hearing the said appeale and that the determination of the said commissioners may be reversed, and such other determination made instead thereof as shall be agreeable to the petioners claim exhibited before the said commissioners—It is ordered by his Majesty in council that the said petition and appeale (a copy whereof is hereunto annexed) Be and it is hereby referred to the Right Honorable the Lords of the committee in council for hearing appeals from the Plantations to hear the same and report their opinion thereupon to His Majesty at the Board.

A true copy.

I. B. LENNARD.

Collated with the original entry in the Council Registry, 18 of Jan'y, 1845.

ROBT. LEMON.

[Ordered in Council, dated 28th May, 1746. Council office. Council Register. Geo. II, No. 10, p. 68.]

AT THE COURT OF KENSINGTON,
*the 28th day of May* 1746.

Present the Kings Most Excellent Majesty in Council.

Upon reading at the Board a Report from the Right Honourable the Lord of the committee of council for hearing appeals from the Plantations dated the 11th of December 1744 in the words following vizt.

Your Majesty having been pleased by Your Order in council of the 29th of July 1742 to refer unto this committee the humble petition and appeale of the Governor and company of the English Colony of Rhode Island and Providence Plantations in New England in America, from several particular parts of the determination of the commissioners appointed by your Majesty to settle the Boundarys of said colony eastwards with the Province of Massachusetts Bay and humbly praying that the particular parts of the said commissioners determination appealed from may be reversed, and such other determinations made instead thereof, as shall be agreeable to the true construction of the Boundarys continued in the Royal Charter under which the petitions claim—and your Majesty having been also pleased by another order in council of the 15th of September 1742, to refer unto this committee, the humble Petition and appeal of your Majesty's Province of the Massachusetts Bay in New England parte of

the said determination of the said commissioners, and humbly praying that the same may be reversed and set aside and that instead thereof Your Majesty will be graciously pleased to give such judgement and determinations as shall be agreeable to the petitioners claim exhibited before the said commissioners. The Lords of the committee in obedience to your Majesty's said orders of Reference, have met several times, and taken both the said Petitions of Appeale into their consideration, and having examined into the Proceedings of the said commissioners, do find that they pronounced their judgements or determination on the 30th of June 1741 in the words following:

The court took into consideration, the charters, Deeds and other Evidences, Claims Pleas and allegations produced and made by party refering to the controversy before them and after mature advisement, came to the following Resolutions: That there is not any one Evidence proving that the Water between the Main Land on the East, and Rhode Island on the West, was ever at any time called Naragansett River, that though there be evidence that the place where the Indian called King Philip lived near Bristol, was called Pawconoket, and that another place near Swanzey was called Sowams or Sowamsett, yet no evidence has been produced of the extent of the Pawconoket country to Seaconk, or Pawtucket River, as it runs to the line of the late Colony of the Massachusetts Bay, for tho' there be some evidence that the Indians at enmity with King Philip, or with other Indians in enmity with him, lived on the west side of the said River, and that the Indians subject to King Philip, or in amity with him, lived on the East side of the said River there is no Evidence that all the Indians subject to, or in amity with King Philip, lived in the Pawconoket Country. That the Province not having produced the Letters Patent, constituting the council of Plymouth, nor any copy thereof, the Recital of said Letters Patent in the deed from the council of Plymouth, to Bradford and his associates, is not sufficient evidence against the Kings Charter. That the council of Plymouth being a Corporation, could not create another corporation, and that no Jurisdiction within the Kings Dominions in America can be held by Prescription or on the Foot of Prescription. That the determination of the boundarys of the colony's of Rhode Island and New Plymouth by the Kings Commissioners in the year 1664 appear to have been only a temporary order for preserving the Peace on the Borders of both Colonys without determining the Rights and Titles of either. Upon the whole nothing appears whereby the Colony of Rhode Island and Providence plantations can be barred or hindered from extending their Jurisdiction Eastward towards the Province of the Massachusetts Bay according to the true intents and meaning of their charter. But some dispute having arisen between the Partys as to the true construction and meaning thereof, the court is of opinion, That the Narragansett Bay is and extendeth itself from Point Judith in the west to Seaconet Point on the East and including the Islands therein, layeth and extendeth itself unto the mouth of the River which runuith towards the town of Providence and that as it so lies or extends, it has and may be considered as having one Eastern Side at the Eastern coast of the said Bay runs up northerly from Seconets Point,—and one other North Eastern Side from near Mount Hope to Bullocks Neck, as the said Bay runs up North Westerly towards the Town of Providence and that the land adjacent to the said North Eastern and Eastern Coasts and including within the following lines and the said Bay are within the Jurisdiction of the Colony of Rhode Island; Vizt on the North East side of the said Bay—one line running from the south west corner of Bullocks Neck, Northeast three Miles. One other line running from the Northeast extremity of the said line until it be terminated by a line three miles Northeast from the northeasternmost part of the Bay on the west side of Rumstick Neck, and one other line from the termination of the west line to the Bay at or near Towoset Neck, running so that it touch the North East extremity of a line running three miles North East from the North East corner of Bristol Harbour, and on the Eastern side of the said Bay; One line from a certain point on the Eastern side of the said Bay opposite to the southernmost part of the Shawmuts Neck, and

Providence Plantations, towards the Massachusetts Bay, is, shall be and run
a certain Pointe (where a Meridian line passing through Pawtuckets Falls
the South Boundary of the Colony of Massachusetts Bay), south to Pawtu
Falls, Then southerly along the eastward side of Seaconk River, and the
which runnith towards the Town of Providence, to the Southwest corner of Bul
Neck, then Northeast three miles; and then along the aforesaid lines running at
miles distance from the Easternmost parts of the said Bay to the said Bay, at o
Towoset Neck. Then as the said Bay runs to the southernmost point of Shaw
Neck, and then in a straight line to the aforesaid point opposite to the said
Then East three miles and then along the aforesaid lines, running at three mile
tance from the Easternmost parts of the said Bay, to the sea. All which lines
be run by making the proper allowance for the variation of the Magnetic Needle
the Meridian. And for the better understanding of the description of the lines
mentioned; the Court hath caused the Boundary lines of the lands adjacent
said most eastern and Northeastern points of the Said Bay, to be delineated o
Map or Plan of the said Bay and countries adjacent now in court, and the sam
distinguished on the said Map or Plan, by A, B, C, D, E, F, G, H.

The Lord of the Committee having considered the whole matter and hear
partys concerned therein by their Council learned in the Law, Do agree humb
report to your Majesty as their opinion, That the said Judgment or determinati
the said Commissioners should be affirmed, and both the Petitions of Appeal
from dismissed.

His Majesty this day took the said Report into consideration and was pleased
the advice of the Privy Council to approve thereof, and to order, that the said
ment or Determiuation of the said Commmissioners, Be, and it is hereby Affirmed
both the said Petitions of Appeal therefrom dismissed.

Whereof the Governor or the Commander in Chief of His Majesty's Province
Massachusetts Bay, The Governor and Company of the colony of Rhode Island
Providence Plantations for the time being, and all others whom it may concer
to take notice and govern themselves accordingly.

A true Copy.

I B LENNA

Colated with the Original entry in the Council Register, 18 January, 1745.

ROBT LEM

Under the foregoing decree the line was run by commissioner

from Pawtucket Falls to the south boundary of the aforesaid province of the Massachusetts Bay, in manner following, viz: From a certain point on the southern side of Pawtucket Falls, where we erected a monument of stones, with a stake thereon, we run a meridian line which directly passed through said falls, to a walnut tree on the northerly side of said falls; then to a pitch pine tree; then to a small white oak; then to a grey oak; then to a small bush; then to another small bush with stones about it; then to a heap of stones with a stake thereon; then to a black oak tree; then to another black oak; then to a small pitch pine; then to a black oak; then to a large white oak near the river, called Abbot's Run; then to a poplar tree; then to a heap of stones with a stake thereon; then to a large rock with stones thereon; then to a small black oak tree; then to a walnut tree; then to a black oak; then to divers other marked trees in the said course, to the extremity of said line; and when we came near the termination of the said line made a monument of stones, there being no noted south boundary of the said province near the said line, and therefore, for the discovery of the south boundary of the said province, upon the best information we could obtain, proceeded to Wrentham Plain, at or near to a place where was formerly erected a stake, called Woodward's and Saffery's stake, as one remarkable south boundary of the said province, and from thence run a west line, making an allowance of eight degrees and a half as the west variation of the magnetic needle from the true meridian, it being the course of the south line of the said province, according to their charter (as we apprehended), and then we extended the said north line from the aforesaid monument till it intersected the said west line, and upon the point of its intersection erected a monument of stones with a stake thereon, as the northeast boundary of that tract of land commonly called the Gore.

After which we proceeded to Bullock's Neck, and on the southeast corner thereof erected a red cedar post, marked with the letters J. H. C. R., with the figure of an anchor thereon, and from thence running a line northeast making the same allowance for the variation aforesaid, to a black oak tree marked with the letters G. C. C. R., then to a large white oak marked with the letters G. B. C. R., then to a white oak post, set in the ground with a heap of stones around it, marked with the letters G. W. C. R., with the figure of an anchor thereon, being three miles distant from Bullock's Neck aforesaid.

After which we proceeded to the northeasternmost part of the bay on the west side of Rumstick Neck, and from a point where a locust post was erected, run a line three miles northeast, with the same allowance for the variation and at the extremity of the said line erected a monument of stones, from which we run a line to the northeast extremity of that line drawn from the southwest corner of Bullock's Neck aforesaid, the course whereof being west thirty-eight degrees north, according to the magnetic needle, the distance of nine hundred and fifty-five rods, marking trees and making other boundaries in the course of said line. After which we proceeded to the northeast corner of Bristol Harbour, and from high-water mark, which was some rods distant northeast from the bridge leading to Swanzey Ferry, we ran a line three miles northeast, still making the same allowance for the variation, and at the extremity of which line we erected a monument of stones; then we ran a line from the northeast extremity of the line drawn from Rumstick aforesaid, the course whereof being south twenty-five degrees east, till it met with the termination of the line drawn from Bristol Harbour aforesaid, the distance whereof being nine hundred and twenty-seven rods; and from thence to a straight line to the bay at Towoset Neck, making proper boundaries in the course of said line.

After which we proceeded to the eastern side of the Narragansett Bay, and on the easternmost part of a cove in the said bay, which is southward of Nanequachet, ran a line three miles east (still making the same allowance for variation), at the extremity whereof we marked a grey oak tree with the letters C. R., with the figure of an anchor thereon.

After which we proceeded to the mouth of Fall River, and from thence measured

four hundred and forty rods southerly on the shore, as the said shore extendeth itself from the mouth of said Fall River, and from the point where the said four hundred and forty rods reached, being east thirty-five degrees south of the southernmost point of Shawomet Neck, we ran a line three miles east, with the same allowance for the variation; in the course whereof we marked divers trees, and came to a large pond, on the west of which was a small oak between two large rocks, and from thence measured over the said pond to a bunch of maples, two whereof we marked with the letters I and F, standing on a place called Ralph's Neck, being the extremity of the said three miles; from thence we ran a line south twenty degrees west, two thousand one hundred and twenty-three rods (making proper boundaries in said line), till we met the termination of the three-mile line, ran from the cove southward of Nanequachet aforesaid.

After which we proceeded to a place called Church's Cove, in said bay, and ran a line three miles east, making the same allowance for the variation aforesaid, and at the extremity whereof, and near the sea, we erected a monument of stones, and from thence ran a line north two degrees and a quarter east, one thousand and nine hundred and forty-one rods, till it also met the termination of the said line, drawn from the first mentioned cove as aforesaid, making proper boundaries in the course of said line.

The aforegoing is a just account of our proceedings, and report the same accordingly.

J. HONEYMAN, Jr.
GEORGE WANTON.
GIDEON CORNELL.
GEORGE BROWN.

And it is voted and resolved, That the said report be, and it is hereby, accepted by this assembly.

In the year 1748 the legislature of Rhode Island appointed commissioners to continue the line to the Connecticut River, recognizing the Woodward and Saffrey stake as the place of beginning. Massachusetts failed to appoint commissioners, whereupon the Rhode Island commissioners proceeded to complete the running of the line. In their report they say—

That we not being able to find any stake or other monument which we could imagine set up by Woodward and Saffrey, but considering that the place thereof was described in the agreement mentioned in our commission, by certain invariable marks, we did proceed as followeth, namely: We found a place where Charles River formed a large current southerly, which place is known to many by the name of Pappatalish Pond, which we took to be the southernmost part of said river, from the southernmost part of which we measured three English miles south, which three English miles did terminate upon a plain in a township called Wrentham. (See Howard's Reports S. C., vol. 4, page 632).

From this point they ran the line. From this time forward repeated steps were taken by Rhode Island by resolutions, and by appointment of commissioners at different times to ascertain and run the line, in connection with commissioners from Massachusetts; commissioners from both colonies met more than once, but they failed to agree upon a boundary in place of that established under the agreements of 1711–'18. Rhode Island alleged a mistake in her commissioners, in the place of beginning (that is, on Wrentham Plain), as the ground of these efforts.

This controversy, however, embraced the entire line from the State of

Connecticut to the Atlantic Ocean. Massachusetts asserted that an encroachment had been made on her territory from Burnt Swamp Corner to the ocean by Rhode Island, who, on her part, claimed that the jurisdictional line of Massachusetts from said corner to the Connecticut line was, in its whole extent, upon the territory of Rhode Island. The legislatures of the respective States having failed, after repeated effort, to adjust the controversy, Rhode Island in 1832, by a bill in equity, brought the subject of the northern boundary, from Burnt Swamp Corner to the Connecticut line, before the Supreme Court of the United States, which in 1846 decided that the jurisdictional line claimed by Massachusetts was the legal boundary of the two States between these points.

While this suit was pending an attempt was made to settle the long controversy by an amicable adjustment of the whole line from Connecticut to the ocean. Commissioners were appointed by both States in 1844 to ascertain and mark the true boundary from Pawtucket Falls to Bullock's Neck. In 1845 the same commissioners were authorized to ascertain the line from Burnt Swamp Corner to the Atlantic Ocean.

In 1846, the equity suit having been decided, they were authorized "to erect suitable monuments at the prominent angles of the line, from the Atlantic Ocean to the northwest corner of Rhode Island, and at such other points on the line as may subserve the public convenience." A majority of said commissioners agreed upon a line and erected monuments in 1847.

The report of the joint commission was dated Boston, January 13, 1848.

The line so agreed upon as a boundary between Burnt Swamp Corner and the northwest corner of Rhode Island was a straight line, varying a little from the irregular jurisdictional line established by the decision of the Supreme Court, and is described in the joint report of the majority of the commissioners of January, 1848, as follows, viz:

Begin at the northwest corner of Rhode Island, on Connecticut line, in latitude 42° 00′ 29″ north, and longitude 71° 48′ 18″ west of Greenwich, thence easterly in a straight line 21.512 miles to Burnt Swamp Corner, in Wrentham, being in latitude 42° 01′ 08″ and longitude 71° 23′ 13″.

Upon this line were placed twenty-seven monuments, exclusive of that at Burnt Swamp Corner.

The general assembly of Rhode Island, in May, 1847, ratified and established the line from the ocean to the Connecticut line, "to take effect and become binding whenever the said agreement and boundary line should be ratified by the State of Massachusetts." The legislature of Massachusetts did not ratify the said agreement and boundary line, but proposed another joint commission, which was agreed to.

The attempt made by these commissioners to settle the line having failed, Massachusetts commenced a bill in equity before the Supreme Court of the United States for an adjudication of the boundary line from Burnt Swamp Corner to the Atlantic Ocean.

In 1860 both States agreed upon a conventional line, and asked that a decree of the United States Supreme Court should confirm the same, which prayer was granted, and the line was thus finally established by a decree rendered in the December term, 1861, which is as follows, viz:

Beginning at Burnt Swamp Corner (so called), in Wrentham, in latitude 42° 01′ 08″ north, longitude 71° 23′ 13″ west of Greenwich, being the northeasterly corner of Rhode Island.

Thence in a straight line to the center of a stone monument in the division line, between Attleborough and Pawtucket, on the easterly bank of the Blackstone River, being in latitude 41° 53′ 36″ north, longitude 71° 23′ 14″ west.

Thence easterly, by the northerly line of the town of Pawtucket, to a point where said line intersects the highest water mark on the easterly side of Farmer's or Seven Mile River, which point is shown on accompanying sheet marked "A," and designated as "Bound No. 1," being in latitude 41° 53′ 54″ north, longitude 71° 20′ 40″ west.

From Bound No. 1 the line runs southerly, following the highest water mark on the easterly side of Farmer's or Seven Mile River, as designated in said sheet marked "A," to its junction with the highest water mark on the southerly and easterly side of Ten Mile River, at a point designated as "Bound No. 3."

From Bound No. 3 the line runs southerly, following the highest water mark on the southerly and easterly side of said Ten Mile River, as shown on sheet marked "A," to a point designated as "Bound No. 13," said last point being at the most southerly bend of Ten Mile River in said line of highest water mark.

The line of "highest water mark" as shown on sheet A is defined by offsets at right angles to straight lines shown on said plan in blue ink, from Bound No. 1, and passing through points designated as bounds numbered 2 to 13, inclusive.

From Bound No. 13 the line runs southeasterly, being a straight line to the center of a stone pier in the middle of Runnin's River, on the north side of the road leading by Luther's store.

Thence through the center or middle of said Runnin's River as the same is at low water at a point when such line intersects the dividing line between Barrington and Seekonk, being in latitude 41° 46′ 28″, longitude 71° 19′ 23″.

Thence northeasterly, following the dividing line between Barrington and Seekonk, to a point at the northerly extremity of the dividing line between Barrington and Swanzey, in latitude 41° 36′ 34″, longitude 71° 19′ 30″.

Thence in a straight line southeasterly to the center of a copper bolt in King's Rock, so called and well known, near an ancient monument on said King's Rock, being on the west side of the road leading from Warren to Swanzey. This point is in latitude 41° 45′ 22″.98, longitude 71° 16′ 35″.75.

From King's Rock the line follows the dividing line between Warren and Swanzey to Mount Hope Bay, running in a straight line southeasterly to a point on the Birch Swamp Farm, in latitude 41° 45′ 08″, longitude 71° 15′ 58″.5.

Thence in a straight line to Mount Hope Bay, passing through the center of a copper bolt in a bowlder, in line of extreme high water at Toweset, to low-water line of said bay. This bolt is in latitude 41° 42′ 45″.27, longitude 71° 13′ 54″.70.

From Toweset the line runs southeasterly, crossing Mount Hope Bay, to the westerly end of line dividing Fall River and Tiverton, where the same intersects low-water line of said Mount Hope Bay.

Thence easterly, following said dividing line between Fall River and Tiverton, passing through the middle of a town way on the north side of farm belonging to John Chase, and through the southerly end of Cool's Pond, in a line passing through the middle of a highway, eight rods wide.

Thence running southerly through the center of said eight-rod highway to a point in line with the stone wall on northerly side of farm of Edmund Estes. This wall is easterly of the Stafford road (so called.)

Thence running easterly in line with said wall to a point in line of highest water mark on the westerly shore of South Watuppa Pond, which point is shown on accompanying sheet marked "B," and designated as "Bound A."

From Bound A the line runs southerly, following the highest water mark on westerly side of South Watuppa Pond, and of Sawdy Pond, and of the streams connecting said ponds, as shown on said sheet marked "B," to a point designated as "Bound F," said last point being at the most southerly end of Sawdy Pond in said line of highest water mark.

The line of "highest water mark" as shown on sheet B is defined by offsets at right angles to straight lines from Bound A, and passing respectively through points designated "B" to "F," inclusive, and on the South Watuppa Pond is also the line that would be traced by a level thirteen inches above a bolt in stone work on westerly side of waterway in gate-house of reservoir dam of Watuppa Reservoir Company, Quequechan River. On Sawdy Pond the highest water mark is the line that would be traced by the level of an iron bolt driven in west side of flume to sawmill at northerly end of said Sawdy Pond.

From Bound F the line runs southeasterly, being a straight line to the monument known as "Joe Sanford's bound," being the center of a copper bolt in stone on land of Joseph Tripp, and is in latitude 41° 35′ 37″ longitude 71° 08′ 13″.

From Joe Sanford's bound the line runs southerly, following the westerly line of the town of Westport to the Atlantic Ocean, passing easterly of Quicksand Pond through the center of a bound known as Peaked Rock, situated in latitude 41° 29′ 58″, longitude 71° 07′ 34″.

The first point in this line southerly of Sanford's bound is on the north side of milldam at Adamsville, 85.58 feet easterly of straight line from Sanford's to Peaked Rock.

The second is 113.94 feet easterly of said straight line, and is on the easterly side of road leading from Adamsville to the ocean.

The third is 234.48 feet east of said straight line, on the road leading to Little Compton, by Philip Simmons' house.

The whole of the line thus described is shown on a plan herewith presented, which, with Sketches A and B, is made a part of this report and attested.

It will be observed that the above decree of the United States Supreme Court makes no reference to the line from Burnt Swamp Corner to the Connecticut line.

It will also be remembered (*vide* p. 55) that the "line of 1848," so called, was ratified by Rhode Island and rejected by Massachusetts. In 1865 the legislature of Massachusetts took action in regard to this portion of the line, as follows, viz:

*Resolved*, That the boundary line between the State of Rhode Island and the Commonwealth of Massachusetts, from the line of the State of Connecticut to Burnt Swamp Corner, begins at the northwest corner of the State of Rhode Island on the Connecticut line, in latitude 42° 00′ 29″ north, and longitude 74° 48′ 18″ west of Greenwich,[3] and runs in a straight line 21 add $\frac{444}{1000}$ miles to Burnt Swamp Corner, in Wrentham, being in latitude 42° 1′ 8″ and longitude 71° 23′ 13″.

This is the line agreed upon by the commissioners, called the "line of 1848," ratified at the time by Rhode Island, but rejected by Massachusetts.

The tardy ratification of the line by Massachusetts was, in its turn,

[3] This is a clerical error. "Longitude 74° 48′ 18″" should read "longitude 71° 48 18″." (*Vide* Borden's Tables, p. 64).

rejected by Rhode Island, on the ground that the then recent settlement of the eastern boundary by the decree of the Supreme Court had so changed the aspect of the controversy that she could not consent to the adoption of the line of 1848 as her northern boundary.

Thus the northern boundary of Rhode Island was left in abeyance, or rather left in the condition prescribed by the decision of 1846.

In June, 1880, the legislature of Rhode Island passed a resolution to remove the monuments of the "line of 1848" and erect monuments on the jurisdictional line.

In 1881 the legislature of Massachusetts took like action.

This jurisdictional line has the same termini as the line of 1848, but is a very irregular line, sometimes running north of a direct line and sometimes falling south of it [the extreme variations being 529.3 feet north of the line of 1848, and 129 feet south of the same.] A full and detailed description may be found in Rhode Island acts, May, 1867, p. 6 *et seq.*

Also, *vide* Senate Document No. 14, Massachusetts, 1848, for a full account of this controversy.

In 1713, commissioners from the Province of Massachusetts Bay and Colony of Connecticut settled a line between Massachusetts and Connecticut.

By this line certain northern frontier towns were given to Massachusetts, viz: Woodstock, Suffield, Enfield, and Somers. In 1749 the legislature of Connecticut passed a resolution that, inasmuch as the line had not been approved by the King, and that the two colonies had no legal right to transfer territory without the confirmation of the Crown, the contract was void, and these towns were again taken under the jurisdiction of Connecticut. Massachusetts appealed to the King, and the claims of Connecticut were fully established. (See Hollister's History of Connecticut, Vol. II.)

In 1791 Massachusetts and Connecticut appointed commissioners to establish the boundary between them, but they were unable to agree.

In 1803 commissioners were appointed to complete the line, a compromise having been made concerning the line between the town of Southwick and the towns of Suffield and Granby (the cause of the disagreement of the former commissioners).

The agreement made was as follows, viz:

> That the line should begin from a station 8 rods south of the southwest corner of West Springfield, and thence run west to the large ponds, and thence southerly by those ponds to the ancient south line of Westfield, and from thence on said south line to the ancient southwest corner of Westfield; and from thence northerly in the ancient west line of Westfield to the station in said west line made by commissioners in the year 1714, and from thence to the southwest corner of Granville. (See Mass. Special Laws, Vol. III, page 234.)

In 1803 the commissioners surveyed and marked the boundary between their respective States.

Their report, which was adopted, is as follows, viz:

Beginning at the northeast corner of Suffield and the southeast corner of West Springfield, on the west bank of Connecticut River, at a point 75 links northward of the center of a small valley running into said river, said point being between a small butternut tree, marked M. C., standing on the south, and a small crooked white oak, marked M., standing on the north, about two feet distant from each other, and then run north 82° 45′ west 1 chain to a stone monument erected by us there; in the same course 22 chains 25 links to a stone monument on the stage road from Springfield to Suffield, and said course continued would pass two feet north of Smith's house; thence north 82° west 82 chains 3 links to a stone monument on the middle road from Suffield to Springfield; then in the same course 13 chains 30 links to a large black or red oak tree, marked on the east side C., and on the west side M., being an ancient bound; thence north 77° 4′ west 134 chains 42 links to a stone monument on the road from Feeding Hills meeting-house to Suffield; thence in the same course 4 chains 21 links to a pine stump—an old monument; thence north 79° 48′ west 102 chains 80 links to a stone monument on the road from Westfield to Suffield, called the back street; thence north 81° 30′ west 61 chains 20 links to a stone monument at an old stump and stones, the ancient southwest corner of West Springfield; thence south 5° west 2 chains to a stone monument in the line run by commissioners in 1714; thence north 85° west 167 chains 33 links to a stone monument at the middle pond, 22 links east of low-water mark, being at the center of a little valley running into said pond; thence on the eastern shore of said pond, as the same runs southerly, to a sluice way or outlet from said pond to the south pond; thence southerly on the east shore of the south pond as the same runs to a stone monument at high-water mark on the south corner of said pond, being the south end of the most southerly bay thereof, from which the point of land beyond the bay on the east side of the pond bears north 29° east, and the high point beyond the bay on the west side of the pond is north 3° 30′ east; then south 10° 20′ west 24 chains 78 links to a stone monument at the southeast corner of Southwick, in the ancient south line of Westfield, from which the highest peak of Manatick Mountain bears south 42° 30′ west; thence south 87° 30′ west 33 chains 86 links to a heap of stones in a hedge, being an ancient monument in the south line of Westfield and the northwest corner of Suffield, adjoining Granby; thence in said ancient south line of Westfield the same course to a stone monument at a white oak stump, an old monument, the southwest corner of Southwick, being 174 chains 36 links; thence north 10° 20′ east 212 chains 84 links to a stone monument erected by us, at a place in the ancient west line of Westfield, where commissioners in 1714 established the monument called the Crank monument; thence north 82° 17′ west 137 chains to a stone monument erected by us at the east road from Granby to Granville; in this course, at the distance of 86 chains 20 links from the Crank monument, we passed between two pillars of stones 45 links south of one and 13 links north of the other, both said to be the southeast corner of Granville; thence on the same course 61 chains 40 links to a stone monument erected by us on the Granby turnpike road; thence in the same course 44 chains to a white-oak[4] tree, marked by commissioners in 1717, and which we marked M on the north side and C, 1803, on the south side; thence north 84° 24′ west 5 chains 13 links to a stone monument erected by us on the west road from Granby to Granville; thence in the same course 200 chains 37 links to a white elm stump and stones on the west bank of Valley Brook, so-called, a monument, made by commissioners in 1717 in this course three monuments are mentioned by said commissioners, which we do not find; thence north 85° 7′ west 60 chains 15 links to a stone monument erected by us at a new road near the east bank of Hubbard River; thence the same course 2 chains to dry hemlock tree with stones about it on the west side of said river near a small fall and a rock on the east side of said river stooping towards it more than 2

[4] Oak-tree boundary at Granville, marked in 1717.

rods to a monument erected by said former commissioners; thence north 82° 52′ west 109 chains 35 links to a stone monument[5] erected by us on the road from Granville to Hartland; thence the same course 275 chains 91 links to a large heap of stones on the west bank of Slocum Brook between two hemlock trees, having many ancient and modern marks thereon, being a monument made by said former commissioners; in this course, the commissioners of 1717 made mention of a large hemlock tree, and a very large white-ash tree which we do not find; thence north 81° 50′ west 93 chains 74 links to a stone monument erected by us on the Beach-hill Road, so-called; thence in the same course 235 chains to a stone monument erected by us at a heap of stones about an elm tree standing on the west bank of Sandy Brook, a monument made by said former commissioners, who mentioned in their report a monument in this course, which we do not find; thence north 82° 11′ west 357 chains 30 links to a stone monument erected by us on the road from Marlborough to Norfolk; thence same course 38 chains 20 links to a monument made by said former commissioners on the west bank of Whiting River, near falls, being a heap of flat stones on a large rock; thence north 82° 9′ west 219 chains to a stone monument at the end of Greenwood Turnpike road; in this course said former commissioners marked two trees, which we do not find; thence in the same course 161 chains 75 links to a stone monument at the Burrell Road, so-called, leading from Canaan to Suffield; thence in the same course 49 chains to an elm tree, with stones near it, on the east bank of Housatonic River, about six rods west from a chestnut stump and stones, a monument made by said former commissioners, who also marked a white oak tree in this course which we not find; thence north 82° 52′ west 20 chains 50 links to a stone monument erected by us at the road leading from Salisbury to Sheffield, called Wetany Road; thence in the same course 119 chains 50 links to a stone monument erected by us at the road from Salisbury to Sheffield, near Ebenezer Fletcher's house; thence on the same course 211 chains 35 links to a stone monument erected by us at the mountain road from Salisbury to Sheffield; thence on the same course 28 chains 4 links to a monument established by said former commissioners at the foot of the mountain, being a heap of stones on a large rock, 20 links long on the northeasterly side, 5 feet high on the southerly side, and which we marked 1803 on the southerly side; thence north 85° 30′ west 147 chains 20 links to a stone monument erected by us on the road from Salisbury to Mount Washington; thence on the same course 81 chains 80 links to a large heap of stones, the oblong corner bounds, so-called between the State of Connecticut and New York.

* * * * * * *

The courses of said line as before given, and here by us are according to the present state of Magnetic needle, which we observed to vary 5° west of north. (See Private Laws of Conn., vol. 2, pages 1540 to 1544.)

ABSTRACT OF REPORT OF COMMISSION OF 1803 ON BOUNDARY BETWEEN MASSACHUSETTS AND CONNECTICUT WEST OF THE CONNECTICUT RIVER.

Beginning at a point on the west bank of Connecticut River, in latitude 42° 01′ 52″.10, longitude 72° 37′ 03″.46, and running north 82° 45′ west 22 chains 25 links; thence north 82° west 95 chains 33 links; thence north 77° 4′ west 138 chains 63 links; thence north 79° 48′ west 102 chains 80 links; thence north 81° 30′ west 61 chains 20 links; thence south 5° west 2 chains; thence north 85° west 167 chains 33 links to a stone monument at the middle pond, 22 links east of low-water mark, latitude 42° 02′ 11″, longitude 72° 45′ 45″.07; thence southerly along the east shore of said pond, and also south pond, to a stone monument at high-water mark, at the south corner of said south pond; thence south 10° 20′ west 24 chains 78 links to a stone monument at southeast corner of Southwick, which is in latitude 42° 00′ 11″.98, lon-

[5] Boundary stone in west front of Granville.

gitude 72° 46′ 24″.23; thence south 87° 30′ west 208 chains 22 links to a stone monument at the southwest corner of Southwick, which is in latitude 41° 59′ 51″.89, longitude 72° 49′ 25″.47; thence north 10° 20′ east 212 chains 84 links, to a stone monument at the northwest corner of the Southwick Jog, which is in latitude 42° 02′ 12″.39, longitude 72° 49′ 13″.51; thence north 82° 17′ west 242 chains 40 links to a white oak tree, marked by commissioners in 1717, which is in latitude 42° 02′ 15″.84, longitude 72° 52′ 47″.74; thence north 84° 24′ west 205 chains 50 links; thence north 85° 7′ west 62 chains 15 links; thence north 82° 52′ west 109 chains 35 links to a stone monument in latitude 42° 02′ 17″.03, longitude 72° 58′ 22″.52; thence north 82° 52′ west 275 chains 91 links; thence north 81° 45′ west 70 chains; thence north 81° 50′ west 328 chains 74 links to a stone monument, which is in latitude 42° 02′ 31″.11, longitude 73° 07′ 35″.94; thence north 82° 11′ west 395 chains 50 links; thence north 82° 9′ west 430 chains; thence north 82° 52′ west 140 chains to a stone monument on the road from Salisbury to Sheffield, which is in latitude 42° 02′ 58″.11, longitude 73° 22′ 55″.27; thence north 82° 52′ west 239 chains 39 links; thence north 85° 30′ west 239 chains to the northwest corner of Connecticut, which is in latitude 42° 02′ 58′.54, longitude 73° 30′ 06″.66.

According to the survey of the cession of Boston Corners, by Massachusetts to New York, in 1855, the south boundary of Massachusetts from the northwest corner of Connecticut to the southwest corner of Massachusetts is as follows, viz:

A line running north 89° 08′ 4″ west, 40 chains, by the true meridian.

The courses of the line of 1803 are magnetic, with the variation as at that date: *i. e.*, 5° west.

The latitudes and longitudes in the foregoing are taken from the Borden Trigonometrical Survey of Massachusetts of 1843.

In 1826, the line between Massachusetts and Connecticut east of the Connecticut River was run by commissioners appointed from each State. An abstract of the commissioners' report is here given:

*Abstract of report of commissioners of* 1826.—The commissioners first made the following survey: Commencing at the northeast corner of Connecticut, at a large pile of stones erected by commissioners of 1734; thence running due west on the latitude of 42° 3′ north to the west line of Woodstock, 15 miles 169 rods 15 links. (This is hereafter referred to as the "first line of latitude.") Thence north 3° west 54 rods 19 links to an old pine tree, the reputed northeast corner of Union; thence due west 25 miles 168 rods to Connecticut River. (This line is hereinafter referred to as the "second line of latitude," and the second line of latitude is 54 rods north of the first.) These lines of latitude were compared with the ancient survey, monuments, evidence, etc., of the line run by the commissioners of 1713; the said lines of latitude were found to vary in sundry places therefrom. Therefore, in order to conform as near as possible to the line of 1713, the line was run as follows, viz:

Beginning at the northeast corner of Connecticut and running west on "first line of latitude" 1,702 rods and 4 links to the road to the Merino road; thence in a direct line 1,372 rods 20 links to the road leading from Muddy Brook, so called, by Pennel May's to Southbridge; this point is 21 rods 10 links north of the "first line of latitude"; thence in a direct

line 360 rods 5 links to the Norwich and Woodstock turnpike (this point is 20 rods and 5 links north of "first line of latitude"); thence in a direct line 954 rods 18 links to the road leading from West Woodstock by Abel Mason's to Southbridge (this point is 10 rods and 22 links north of "first line of latitude"); thence in a direct line 1,247 rods to the road leading from Union by Asher Bodgen's to Holland (this point is 2 rods 14½ links south of "second line of latitude"); thence in a direct line 1,127 rods to the turnpike from Hertford through Stafford and Holland to Worcester (this point is 6 rods 23½ links south of the "second line of latitude"); thence in a direct line 467 rods to an old white-oak tree, an ancient bound, on the road from Stafford by Robert Andruss' to South Brimfield (this point is 1 rod 2 links south of "second line of latitude"); thence in a direct line of 1,615 rods to the road leading from Stafford by Henry Cady's to Monson (this point is 16 rods 15 links south of "second line of latitude)"; thence in a direct line 256 rods to the Tracy road (this point is 12 rods 12 links south of "second line of latitude)"; thence in a direct line 620 rods to the road leading from Stafford by Seth Sheldon's to South Wilbraham (this point is 14 rods 7 links south of "second line of latitude"); thence in a direct line 1,066 rods to the road from Somer's by Walter Ainsworth's to Springfield (this point is 4 rods 1 link *north* of "second line of latitude"); thence in a direct line 523 rods to the road from Somer's by Abel Peas's to Springfield (this point is 6 rods 12 links south of the "second line of latitude"); thence *due west* 645 rods to the ancient line between Springfield (now Long Meadow) and Enfield; thence *south* 80° 30′ *west* by the true meridian 645 rods to a monument at an old oak stump; thence *south* 51° 30′ *west* by the true meridian 164 rods 18 links to a monument at an old pine stump; thence *due west* 349 rods 15 links to a monument on the Connecticut River 12 rods from the shore; thence due west to Connecticut River. On the line are erected 49 monument stones, marked on the north side M and on the south side C.

The commissioners also surveyed and marked the line from the the corner of Connecticut to the corner of Rhode Island, reporting as follows:

Beginning at the monument erected at the northeast corner of said State of Connecticut and running in a direct line to the ancient heap of stones on the north side of the turnpike leading from Hertford to Boston through Thompson and Douglass, where we erected a monument, and thence running in a direct line to the northwest corner of the State of Rhode Island.

(For survey of 1826, see Private Laws of Conn., vol. 2, pages 1544 to 1550.)

The boundary between Massachusetts and New York at an early period became a subject of bitter dispute, New York claiming to the west bank of the Connecticut River under the charters of 1664 and 1674 to the Duke of York, Massachusetts claiming under her old charters to the South Sea. After many fruitless attempts at a settlement, an ar-

rangement was entered into in 1773 fixing the western boundary of Massachusetts where it meets New York territory. The Revolution following soon after, the line was not run. In 1785 Congress appointed three commissioners to run the line, who performed that duty in 1787. The line was as follows, viz:

Beginning at a monument erected in 1731 by commissioners from Connecticut and New York, distant from the Hudson River 20 miles, and running north 15° 12′ 9″, east 50 miles 41 chains and 79 links, to a red or black oak tree marked by said commissioners, which said line was run as the magnetic needle pointed in 1787. (*Vide* Revised Statutes of New York, 1875, p. 122.)

The claims of Massachusetts to western lands were finally settled December 16, 1786, by a joint commission of the two States. By this agreement Massachusetts surrendered the sovereignty of the whole disputed territory to New York, and received in return the right of soil and pre-emption right of Indian purchase west of the meridian passing through the eighty-second mile-stone of the Pennsylvania line, excepting certain reservations upon Niagara River. The title to a tract known as "The Boston Ten Towns," lying east of this meridian, previously granted by Massachusetts, was also confirmed. (*Vide* Hough's N. Y. Gaz., 1872, pp. 25, 26.)

April 19, 1785, Massachusetts executed a deed to the United States. It included all title of the State of Massachusetts to territory west of the present western boundary of New York.

In 1820 Maine, hitherto a part of Massachusetts, was admitted into the Union as an independent State.

In 1853 a small portion of territory in the southwestern corner of Massachusetts, known as Boston Corner, was ceded to New York, and the cession confirmed by Congress in 1855.

The cession of Boston Corner to New York changes the boundary, so that it is now as follows, viz:

Beginning at a monument erected in 1731 by commissioners from Connecticut and New York (known as the Connecticut monument), standing in the south boundary of Massachusetts, latitude 42° 02′ 58″.54, longitude 73° 30′ 06″.66, which is the northwest corner of the State of Connecticut; thence along the south boundary of Massachusetts, north 89° 08′ 41″ west, 40 chains; thence north 12° 57′ 16″ west 207.49[5] chains to a marble post marked on the east side M. S., on the west side N. Y., and on the south side 1853, which is in the line run by United States commissioners in 1787; thence north 15° 12′ 9″ east on the line run by said United States commissioners ([6]47 miles 73.70[5] chains) to a red or black oak tree marked by said United States commissioners, in the south boundary of the State of Vermont, latitude 42° 44′

[6] This distance has been obtained by subtracting the length of the west line of Boston Corner given in survey of 1853 from the entire length of west boundary of Massachusetts as given by the United States commissioners in 1787.

45″.58, longitude 73° 16′ 17″.68. [See Revised Statutes of New York, 1875, page 122; also plat of survey of Boston Corner in 1853, a copy of which is on file in office of clerk of House of Representatives at Washington, D. C.; also, for latitudes and longitudes, see tables of Borden's Survey of Massachusetts, 1843.]

*Latitude and longitude of certain points on the boundary line of Massachusetts.* (*From Borden's Trigonometrical Survey*, 1843.)

| States. | Stations. | Latitude. | Longitude. |
|---|---|---|---|
| | | ° ′ ″ | ° ′ ″ |
| Vermont and Massachusetts. | Northwest corner | 42 44 45.58 | 73 16 17.68 |
| | Rowe and Whitingham Station in Vermont line | 42 44 18.48 | 72 53 07.95 |
| | Leyden and Guilford Station in Vermont line | 42 43 55.78 | 72 38 46.57 |
| New Hampshire and Massachusetts. | Warwick (N. H.) State line station | 42 43 22.01 | 72 19 35.32 |
| | Watitick State line station in Ashburnham (Mass.). | 42 42 41.56 | 71 54 15.84 |
| | Pepperell (N. H.) State line station | 42 42 13.29 | 71 35 32.02 |
| | Pine Tree boundary, State line at Dracut (Mass.) | 42 41 50.78 | 71 19 40.59 |
| | Poplar Hill State line boundary, New Hampshire line at Methuen. | 42 44 12.09 | 71 15 38.72 |
| | Ayres Hill State line boundary at Haverhill, Mass. | 42 48 23.38 | 71 04 11.68 |
| | Brandy Brow Hill, State line corners of Haverhill and Amesbury, Mass. | 42 50 00.61 | 71 03 34.17 |
| | Salisbury Marsh Station | 42 52 19.32 | 70 49 32.11 |
| Connecticut and Massachusetts. | [1]Southwest corner of Massachusetts | 42 02 59.54 | 73 31 42.66 |
| | Connecticut line bound at Mount Washington | 42 02 58.54 | 73 30 06.66 |
| | Boundary stone in Connecticut line on road from Sheffield to Salisbury. | 42 02 58.11 | 73 22 55.27 |
| | Boundary stone in Connecticut line on road from Sandisfield to Colebrook. | 42 02 31.11 | 73 07 35.94 |
| | Boundary stone in Granville, in west part of town. | 42 02 17.03 | 72 58 22.52 |
| | Oak tree boundary in Connecticut State line at Granville, marked in 1717. | 42 02 15.84 | 72 52 47.44 |
| | Boundary stone at northwest corner of Southwick Jog. | 42 02 12.39 | 72 49 13.51 |
| | Boundary stone at southwest corner of Southwick Jog. | 41 59 51.89 | 72 49 25.47 |
| | Boundary stone at southeast corner of Southwick Jog. | 42 00 11.98 | 72 46 24.23 |
| | Boundary stone at northeast corner of Southwick Jog. | 42 02 11.00 | 72 45 45.07 |
| | Boundary stone in Connecticut line on west side of Connecticut River. | 42 01 52.10 | 72 37 03.46 |
| | Boundary stone in Connecticut line on east side of Connecticut River. | 42 01 28.74 | 72 36 36.31 |
| | Rattlesnake Mountain in Connecticut line at Wilbraham. | 42 01 59.66 | 72 24 49.86 |
| | High Rocky Ridge, Connecticut line, in Monson | 42 01 56.09 | 72 21 07.26 |
| | Monson line station in Monson | 42 01 53.92 | 72 16 39.23 |
| | Northeast corner of Connecticut at Douglas | 42 01 25.21 | 71 48 23.66 |
| Rhode Island and Massachusetts. | Northwest corner of Rhode Island at Douglas | 42 00 29.48 | 71 48 18.07 |
| | Burnt Swamp corner, northeast corner of Rhode Island. | 42 01 08.60 | 71 23 13.26 |
| | Munroe's Station, Rhode Island State line at Seekonk. | 41 46 34.54 | 71 19 22.92 |
| | Kings Rock Station, Rhode Island State line at Warren. | 41 45 22.98 | 71 16 35.75 |
| | Towesett Neck Station, in Rhode Island, State line at Swanzey. | 41 42 45.27 | 71 13 54.70 |
| | Joe Sandford's Station, Rhode Island State line at Tiverton. | 41 35 37.66 | 71 08 13.73 |
| | Quicksand Pond, State line boundary stone in Rhode Island line at Westport. | 41 29 58.64 | 71 07 34.38 |

These positions require a correction of from 15″ to 20″ in order to make them conform to modern determinations of position.

[1] This corner was changed by the cession of Boston Corner by Massachusetts to New York in 1855.

## RHODE ISLAND.

The present State of Rhode Island was settled by Roger Williams and other immigrants, who left Massachusetts Bay and established themselves at Providence in 1636.

In 1643 a patent was granted for the Providence Plantation, from which the following are extracts, viz:

* * * * * * *

And wheras there is a tract of land in the continent of America aforesaid, called by the name of the Narraganset Bay, bordering northward and northeast on the patent of the Massachusetts, east and southeast on Plymouth patent, south on the ocean, and on the west and northwest by the Indians called Narigganneucks, alias Narragansets, the whole tract extending about 25 English miles unto the Pequot River and country; and wheras divers English inhabitants of the towns of Providence, Portsmouth, and Newport, in the tract aforesaid, * * * have represented their desire, * * * we * * * do * * * give, grant, and confirm to the aforesaid inhabitants of the towns of Providence, Portsmouth, and Newport a firm and absolute charter of incorporation, to be known by the name of the incorporation of Providence Plantations, in the Narraganset Bay, in New England. * * *

In 1663 Charles II granted a charter to Rhode Island and Providence Plantations, of which the following is an extract:

* * * "All that parte of our dominiones in New-England, in America, conteyneing the Nahantick and Narragansett Bay, and countryes and partes adjacent, bounded on the west, or westerly, to the middle or channel of a river there, commonly called and known by the name of Pawcatuck, alias Pawcawtuck river, and soe along the sayd river, as the greater or middle streame thereof reacheth or lyes upp into the north countrye, northward, unto the head thereof, and from thence, by a streight lyne drawn due north untill itt meets with the south lyne of the Massachusetts Collony; and on the north, or northerly, by the aforesayd south or southerly lyne of the Massachusetts Collony or Plantation, and extending towards the east, or eastwardly, three English miles to the east and north-east of the most eastern and north-eastern parts of the aforesayd Narragansett Bay, as the sayd bay lyeth or extendeth itself from the ocean on the south, or southwardly, unto the mouth of the river which runneth towards the towne of Providence, and from thence along the eastwardly side or banke of the sayd river (higher called by the name of Seacunck river), up to the ffalls called Patuckett ffalls, being the most westwardly lyne of Plymouth Collony, and soe from the sayd ffalls, in a streight lyne, due north, untill itt meet with the aforesayd line of the Massachusetts Collony; and bounded on the south by the ocean." And in particular, the lands belonging to the townes of Providence, Pawtuxet, Worwicke, Nusquammack, alias Pawcatuck, and the rest upon the main land in the tract aforesayd together with Rhode Island, Blocke Island, and all the rest of the islands and banks in the Narragansett Bay and bordering upon the coast of the tracts aforesaid (Ffishers Island only excepted). * * *

(For history of the northern and eastern boundaries see Massachusetts, p. 48.)

In 1703 substantially the present western boundary was settled by an agreement made between the commissioners from the two colonies of Rhode Island and Connecticut, viz: "A straight line from the mouth

of Ashawoga River to the southwest corner of the Warwick purchase, and thence a straight north line to Massachusetts.

The line of 1703 was actually run by Rhode Island, and is still known as the Dexter and Hopkins line.

The two colonies disagreeing, Rhode Island appealed to the King, and the agreement of 1703 was finally established in 1726.

In September, 1728, commissioners from the two colonies met and ran the line.

(For agreement of 1703 and 1728, decisions of English council, etc., see R. I. Hist. Soc. Coll., Vol. III.)

In 1839 commissioners were appointed by Rhode Island and Connecticut to survey and ascertain the line and erect monuments.

The following line was established, viz:

Beginning at a rock near the mouth of Ashawoga River, where it empties into Pawcatuck River, and from said rock a straight course northerly to an ancient stone heap at the southeast corner of the town of Voluntown, and from said rock southerly in the same course with the aforesaid line, until it strikes Pawcatuck River. From the southeast corner of Voluntown a straight line to a stone heap at the southwest corner of West Greenwich; from thence a straight line to the southwest corner of the ancient town of Warwick, and which is now a corner of the towns of Coventry and West Greenwich; from thence a straight line to the northwest corner of the town of Coventry; thence a straight line to the northeast corner of Sterling; thence a straight line to the southwest corner of Burrillville, and thence a straight line to a stone heap upon a hill in the present jurisdictional line between the States of Massachusetts and Rhode Island, and at all of said corners, excepting said Warwick corner, we have erected monuments of stone, marked R. I. and C., and have also placed similar monuments on all the principal roads crossing the line, and at other suitable places.

* * * * * * *

And we have caused the ancient monument which was erected at the Warwick corner in November, 1742, to be reset and a large heap of stones to be made around it. Said monument is marked with the letter C. on one side, and on the other R H O D E. I S L A N D and the traces of other letters and figures. [Extract from Commissioner's Report. See R. I. Acts and Resolves, Jan. 1846, pages 12, 13, 14.]

The above was ratified in 1846.

## CONNECTICUT.

The title by which the people of Connecticut held the country was founded on the old patent granted by Robert, Earl of Warwick, in 1631, to Lord Say and Seal, Lord Brook, Sir Richard Saltonstall, and others, associated under the name of the Plymouth Company.

In 1630 the Plymouth Council made a grant of Connecticut to the Earl of Warwick, their president. This was confirmed by King Charles in 1631, and on the 19th of March, in the same year, the Earl conveyed his title to the Plymouth Company, as before stated. (Dwight's Conn., p. 19, *et seq.*)

A charter was granted by Charles II to Connecticut in 1662, of which the following is an extract, viz:

* * * * * * *

We * * * do give, grant and confirm unto the said Governor and Company, and their successors, all that part of our Dominions in New England in America bounded on the east by Narraganset River, commonly called Narraganset Bay, where the said river falleth into the sea, and on the north by the line of the Massachusetts plantation; and on the south by the sea; and longitude as the line of the Massachusetts Colony, running from east to west, that is to say, from the said Narragansett Bay on the east, to the south sea on the west part, with the islands thereunto adjoining. * *

* * * * * * *

[C. and C., p. 256-7.]

Previous to this time the two colonies of Connecticut and New Haven had continued separate, but under this charter they were united and the charter was accepted April 20, 1665. (C. and C., p. 252.)

The Duke of York having been granted a charter in 1664, by which the lands west of the Connecticut River were embraced in his jurisdiction, the question of boundary immediately arose.

About this time Col. Richard Nichols, George Cartwright, esq., Sir Robert Carr, and Samuel Maverick, esq., had been appointed commissioners by the King, and clothed with extraordinary powers, to determine all controversies in the colonies. The matter was referred to them, who, after a full hearing, determined that the southern boundary of Connecticut was the sea (Long Island Sound), and its western, Mamaroneck River, and a line drawn north-northwest from the head of salt water in it to Massachusetts. The territory south and west of these lines was declared to belong to the Duke of York. (*Vide* Dwight's Connecticut, pp. 159 *et seq.*)

This decision, in effect, decided upon a line 20 miles east of the Hudson River as the boundary, having for a starting point a place on Mamaroneck River.

In 1674 the Duke of York received a new charter in substantially the same terms as that of 1664. New controversies concerning jurisdiction led to a new agreement, by which it was stipulated that a tract of land on Long Island Sound, the bounds of which were described as containing 61,440 acres, should be permanently set off to Connecticut by New York on condition that the former, in exchange, should set off to New York a territory of like extent and of uniform width from the tract on the Sound to the south line of Massachusetts. This agreement was sanctioned by a royal ordinance of the King, and in 1684 the tract on the Sound was surveyed and set off to Connecticut.

The western boundary of Connecticut was run in 1685 by Major Gould, Mr. Barr, and Mr. Selleck, and ratified by both parties. (*Vide* Dwight's Connecticut, p. 199.)

For various reasons the survey of the equivalent lands was not made at that time.

In 1725 commissioners were appointed on both sides to fix the line,

this being the fifth set appointed for the same purpose, none of which had been able to come to an agreement.

The commissioners of 1725, however, entered into articles of agreement settling the manner of the survey. They, however, ran only the line bounding the tract on Long Island Sound.

For some cause action was then suspended until 1731, when the commissioners of 1725 surveyed and set off the oblong or equivalent territory to New York, defining and marking its boundary, which was to remain forever the dividing line between the respective States (then colonies). The line was substantially as at present, and is as follows, viz:

Beginning at Lyon's Point, in the mouth of a brook or river called Byram's River, where it falls into Long Island Sound, and running thence up along said river to a rock at the ancient road or wading-place in said river, which rock bears north twelve degrees and forty-five minutes east, five hundred and fifty rods from said point; then north twenty-three degrees and forty-five minutes west, two thousand two hundred and ninety-two rods; then east-northeast, thirteen miles and sixty-four rods, which lines were established in the year one thousand seven hundred and twenty-five, by Francis Harrison, Cadwaller Colden, and Isaac Hicks, commissioners on the part of the then province of New York, and Jonathan Law, Samuel Eells, Roger Walcott, John Copp, and Edmund Lewis, commissioners on the part of the then colony of Connecticut, and were run as the magnetic needle then pointed; then along an east-northeast continuation of the last-mentioned course, one mile, three-quarters of a mile, and twenty-one rods, to a monument erected in the year one thousand seven hundred and thirty-one by Cadwaller Colden, Gilbert Willett, Vincent Matthews, and Jacobus Bruyn, jr., commissioners on the part of said province, and Samuel Eells, Roger Walcott, and Edmund Lewis, commissioners on the part of said colony, which said monument is at the southeast corner of a tract known and distinguished as the oblong or equivalent lands; then north twenty-four degrees and thirty minutes west, until intersected by a line run by said last-mentioned commissioners, on a course south twelve degrees and thirty minutes west, from a monument erected by them in the south bounds of Massachusetts, which monument stands in a valley in the Taghkanick Mountains, one hundred and twenty-one rods eastward from a heap of stones in said bounds, on the top or ridge of the most westerly of said mountains; then north twelve degrees and thirty minutes east from a monument erected by said last-mentioned commissioners at said place of intersection, and standing on the north side of a hill, southeasterly from the easternmost end of the long pond, along the aforesaid line to the aforesaid monument erected in the south bounds of Massachusetts—being the northeast corner of the oblong. (See Revised Statutes of N. Y., 1881, Vol. I, pages 128–9.)

For more than a century no controversy arose, but subsequent to 1850 questions of jurisdiction were raised, and in 1855 Connecticut made a proposition for a new survey. Several sets of commissioners were appointed, but no agreement being reached, finally, in 1860, pursuant to an act of the legislature of New York, the line was run by the New York commissioners, Connecticut not being represented.

The first section of the act of the New York legislature is as follows, viz:

1. The commissioners appointed by the governor to ascertain the boundary line between the States of New York and Connecticut are hereby empowered and directed

to survey and mark, with suitable monuments, the said line between the two States *as fixed by the survey of* 1731.

The following is an abstract of the engineer's report of the line run under direction of the commissioners from New York, the Connecticut commissioners declining to be present or assist, viz:

Beginning at the northwest corner of Connecticut, at the monument erected by the commissioners of New York and Connecticut in 1731, latitude 42° 02′ 58″.54, longitude 73° 30′ 06″.66; thence south 11° 20′ west, 464 chains, to the [8]47th mile monument; thence south 12° 34′ west, 239 chains, 57 links, to the 44th mile monument point; thence south 11° 33′ west, 160 chains 99 links, to the 42d mile monument; thence south 13° 16′ west, 161 chains 24 links, to the 40th mile monument point; thence south 12° 21′ west, 398 chains 21 links, to the 35th mile monument; thence south 12° 32′ west, 158 chains 96 links, to the 33d mile monument; thence south 11° 44′ west, 243 chains 37 links, to the 30th mile monument; thence south 12° 27′ west, 161 chains 32 links, to the 28th mile monument; thence south 10° 56′ west, 160 chains, to the 26th mile monument point; thence south 11° 39′ west, 320 chains 11 links, to the 22d mile monument; thence south 12° 18′ west, 163 chains 17 links, to the 20th mile monument; thence south 11° 49′ west, 159 chains 9 links, to the 18th mile monument; thence south 12° 19′ west, 157 chains 15 links, to the 16th mile monument; thence south 10° 11′ west, 161 chains 7 links to the 14th mile monument; thence south 10° 51′ west, 313 chains 41 links, to the 10th mile monument point; thence south 12° 24′ west, 155 chains 71 links, to the 8th mile monument; thence south 10° 19′ west, 159 chains 28 links, to the 6th mile monument point; thence south 12° 10′ west, 164 chains 42 links, to the 4th mile monument; thence south 11° 44′ west, 158 chains 99 links, to the 2-mile monument; thence south 14° 10′ west, 109 chains 41 links, to the Ridgefield angle monument;[9] thence south 25° 8′ east, 213 chains 39 links, to the 4th mile monument on the east line of the oblong between the Wilton and Ridgefield angles; thence south 24° 48′ east, 157 chains 63 links, to the 2-mile monument; thence south 24° 14′ east, 167 chains 28 links, to the Wilton angle monument, or southeast corner of the oblong as set off by the commissioners of 1731; thence south 67° 45′ west, 138 chains 76 links, to the southwest corner of the oblong, and being where the survey of 1725 terminated; thence south 65° 44′ west, 90 chains 87 links, to a point considered the original 12th mile monument point; thence south 66° 56′ west, 241 chains 93 links, to a point called the 9th mile monument; thence south 66° 45′ west, 319 chains 12 links, to the 5th mile monument point; thence south 66° 25′ west, 398 chains 40 links, to the angle at the Duke's

[8] The mile monuments referred to are those, at that time remaining, which were established by the Connecticut and New York commissioners of 1731.

[9] The entire distance from the Massachusetts line to Ridgefield angle is 52 miles 35 rods, a difference of only 5 rods from the survey of 1731.

Trees; thence south 23° 38′ east, 172 chains 93 links, to a point which is west-southwest and distant 32 rods from the chimney in the old Clapp house; thence south 24° 21′ east, 224 chains 78 links, to a point opposite the old William Anderson house; thence south 24° 19′ east, 173 chains 7 links, to the great stone at the ancient wading place on Byrom River; thence south 17° 45′ west, 12 chains 60 links, to a rock in the river which can be seen at low tide, in which there is a bolt; thence south 27° west, 55 chains 19 links; thence south 7° 20′ east, 13 chains 45 links; thence south 12° 10′ east, 16 chains 13 links; thence south 2° 40′ east, 9 chains 4 links; thence south 28° 25′ east, 9 chains 54 links; thence south 18° 40′ east, 4 chains 77 links; thence south 11° 55′ west, 6 chains 33 links; thence south 58° 10′ west, to where it falls into the sound. (See report of the commissioners to ascertain and settle the boundary line between the States of New York and Connecticut, February 8, 1861, in which will also be found a complete account of this controversy.)

The latitude and longitude of the northwest corner of Connecticut are taken from Borden's Trigonometrical Survey of Massachusetts.

In 1880 commissioners were appointed by Connecticut and New York. Their report was ratified in 1880.

These commissioners reported as follows, viz:

We agree that the boundary on the land constituting the western boundary of Connecticut and the eastern boundary of New York shall be and is as the same was defined by monuments erected by commissioners appointed by the State of New York, and completed in the year 1860, the said boundary line extending from Byram Point, formerly called Lyon's Point, on the south, to the line of the State of Massachusetts on the north.

And we further agree that the boundary on the sound shall be and is as follows:

Beginning at a point in the center of the channel, about 600 feet south of the extreme rocks of Byram Point, marked No. 0, on appended United States Coast Survey chart; thence running in a true southeast course 3¼ statute miles; thence in a straight line (the arc of a great circle) northeasterly to a point 4 statute miles due south of New London Light-House; thence northeasterly to a point marked No. 1, on the annexed United States Coast Survey chart of Fisher's Island Sound, which point is on the longitude east three-quarters north, sailing course down on said map, and is about 1,000 feet northerly from the Hommock or North Dumpling Light-House; thence following said east three-fourths north sailing course as laid down on said map, easterly to a point marked No. 2 on said map; thence southeasterly to a point marked No. 3 on said map; so far as said States are coterminous. (See Revised Statutes of New York, 1881, Vol., I, page 136.)

The above agreement concerning these boundaries between Connecticut and New York was confirmed by the Congress of the United States on February 26, 1881. (See Revised Statutes of United States, 1881.)

(For the history and present location of the eastern boundary of Connecticut, *vide* Massachusetts, p. 55, and Rhode Island, p. 65. For the northern boundary, *vide* Massachusetts, p. 58.)

Under the charter of 1662 Connecticut claimed a large western territory. Subsequent to the Revolution, however, in 1786, 1792, 1795, and 1800, she relinquished all title to any land west of her present boundary.

## NEW YORK.

The territory included in the present State of New York was embraced in the French and English grants of 1603 and 1606. The Dutch, however, in 1613 established trading posts on the Hudson River and claimed jurisdiction over the territory between the Connecticut and Delaware Rivers, which they called New Netherlands. The government was vested in "The United New Netherland Company," chartered in 1616, and then in "The Dutch West India Company," chartered in 1621.

In 1664 King Charles II of England granted to his brother, the Duke of York, a large territory in America, which included, with other lands, all that tract lying between the west bank of the Connecticut River and the east bank of the Delaware. The Duke of York had previously purchased, in 1663, the grant of Long Island and other islands on the New England coast, made in 1635 to the Earl of Stirling, and in 1664, with an armed fleet, he took possession of New Amsterdam, which was thenceforth called New York. This conquest was confirmed by the treaty of Breda, in 1667.

The following is an extract from the grant of 1664 to the Duke of York:

All that parte of the maine land of New England beginning at a certaine place called or knowne by the name of St. Croix next adjoyning to New Scotland in America and from thence extending along the sea coast unto a certain place called Petuaquine or Pemaquid and so up the River thereof to the further head of ye same as it tendeth northwards and extending from thence to the River Kinebequi and so upwards by the shortest course to the River Canada northward and also all that Island or Islands commonly called by the severall name or names of Matowacks or Long Island scituate lying and being towards the west of Cape Codd and ye narrow Higansetts abutting upon the maine land between the two Rivers there called or knowne by the severall names of Conecticutt and Hudsons River togather also with the said river of Hudsons River and all the land from the west side of Conecticutt to ye east side of Delaware Bay and also all those severall Islands called, or knowne by the names of Martin's Vinyard and Nantukes otherwise Nantuckett togather with all ye lands islands soyles harbours mines minerals quarryes woods marshes waters lakes ffishings hawking hunting and ffowling and all other royalltyes proffitts commodityes and hereditaments to the said severale island lands and premisses belonging and appertaining with theire and every of theire appurtenances and all our estate right title interest benefitt advantage claime and demand of in or to the said lands and premises or any part or parcell thereof and the revercon and revercons remainder and remainders togather with the yearly and other ye rents revenues and proffitts of all and singular the said premisses and of every part and parcell thereof to have and to hold all and singular the said lands islands hereditaments and premisses with their and every of their appurtenances.

In July, 1673, the Dutch recaptured New York and held it until it was restored to the English by the treaty of Westminster, in February, 1674.

The Duke of York thereupon, to perfect his title, obtained a new

grant, in substantially the same terms as that of 1664 (C. and C., p. 1328), of which the following is an extract, viz:

* * * * * * *

All that part of the main land of New England, beginning at a certain place called or known by the name of Saint Croix nexe adjoining to New Scotland in America, and from thence extending along the sea-coast into a certain place called Petuaquim or Pemquid, and so up the river thereof to the furthest head of the same as it windeth northward and extending from the river of Kinebequ and so upwards by the shortest course to the river Canada northwards; and all that island or islands commonly called by the several name or names of Matowacks or Long Ialands, situate and being toward the west of Cape Cod and the narrow Higansuts abutting upon the main land between the two rivers there called or known by the several names of Connecticut and Hudson Rivers, together also with the said river called Hudson's River, and all the lands from the west side of Connecticut River to the east side of Delaware Bay; and also all those several islands called or known by the names of Martin Vinyard and Nantukes, otherwise Nantuckett.

* * * * * * *

By these grants to the Duke of York and the conquest of the Dutch possessions in America, it will be seen that New York originally had a claim to a much larger territory than is now included in her limits. The successive changes in her extent may be sketched as follows, viz:

In 1664 the Duke of York sold the present State of New Jersey to Lord John Berkeley and Sir George Carteret.

In 1682 the Duke of York sold to William Penn his title to Delaware and the country on the west bank of the Delaware, which had been originally settled by the Swedes, then conquered by the Dutch, and which had by them been surrendered to the Duke of York.

In 1686 Pemaquid and its dependencies were annexed to the New England government by a royal order, the Duke of York having acceded to the throne of England.

By the charter of 1691 to Massachusetts Bay, all claim to any part of Maine was extinguished, and the islands of Nantucket, Martha's Vineyard, and others adjacent (hitherto known as Duke's County, New York), were annexed to Massachusetts Bay.

The territory west of the Connecticut River to within about 20 miles of the Hudson River, now forming portion of Massachusetts and Connecticut, were, by agreements and concessions made at various periods, surrendered to those States respectively.

In 1781 New York released to the General Government all the lands to which she had claim west of a meridian extending through the west extremity of Lake Ontario, and in 1790 she gave up all claim to the present State of Vermont and consented to her independence.

By these successive reductions New York was left with substantially her present boundaries.

(For the history and settlement of the eastern boundary of New York, *vide* Vermont, Massachusetts, and Connecticut, *ante* pp. 46, 62, and 67.)

The northern boundary was settled by the treaty of peace in 1783

and by the commission under the sixth article of the treaty of Ghent. (*Vide* pp. 10 and 12.)

The boundary between New York and New Jersey was plainly stated in the grant by the Duke of York to Berkeley and Carteret. (*Vide* New Jersey, p. 76.)

In 1719 attempts were made to have the line run and marked, but nothing seems to have been done to settle the matter permanently till 1769, when commissioners were appointed by the King, who fixed on substantially the present line. (*Vide* R. S. N. J., 1821, pp. 29–34.)

In 1772 this line was confirmed by the legislatures of both colonies, and commissioners were appointed to survey and mark the same.

This line was as follows, viz:

A direct and straight line from the fork or branch formed by the junction of the stream or waters called the Machackamack with the river Delaware or Fishkill, in the latitude of 41° 21′ 37″, to a rock on the west side of the Hudson River, marked by the said surveyors in the latitude of 41°—said rock was ordered to be marked—with the following words and figures, viz: "Latitude 41° north;" and on the south side thereof "New Jersey"; and on the north side thereof "New York"; also, to mark every tree that stood on the line with five notches and a blaze on the northwest and southeast sides thereof, and to put up stone monuments, at 1 mile distance from each other, along the said line, and to number such monuments with the number of miles; the same shall be from the before-mentioned marked rock on the west side of Hudson's River, and mark the words "New Jersey" on the south side, and the words "New York" on the north side, of every of the said monuments. (See R. S. of N. J., 1821, pp. 29–34.)

The above was confirmed by the king in council September 1, 1773.

In the year 1833 commissioners were appointed by New York and New Jersey for the settlement of the territorial limits and jurisdiction of the two States.

In the following year the commissioners made the following agreement, which was ratified by each State and confirmed by Congress, viz:

UNITED STATES STATUTES AT LARGE. TWENTY-THIRD CONGRESS, SESSION I. 1834.

AN ACT giving the consent of Congress to an agreement or compact entered into between the State of New York and the State of New Jersey, respecting the territorial limits and jurisdiction of said States.

ARTICLE FIRST. The boundary line between the two States of New York and New Jersey, from a point in the middle of Hudson River, opposite the point on the west shore thereof, in the forty-first degree of north latitude, as heretofore ascertained, and marked, to the main sea, shall be the middle of the said river, of the bay of New York, of the waters between Staten Island and New Jersey and of Raritan Bay, to the main sea; except as hereinafter otherwise particularly mentioned.

ARTICLE SECOND. The State of New York shall retain its present jurisdiction of and over Bedloe's and Ellis's Islands, and shall also retain exclusive jurisdiction of and over the other islands lying in the waters above mentioned and now under the jurisdiction of that State.

ARTICLE THIRD. The State of New York shall have and enjoy exclusive jurisdiction of and over all the waters of Hudson River lying west of Manhattan Island and to the south of the mouth of Spuytenduyvel Creek; and of and over the lands covered by the said waters to the low-water mark on the westerly or New Jersey side thereof; sub-

ject to the following rights of property and of jurisdiction of the State of New Jersey, that is to say:

1. The State of New Jersey shall have the exclusive right of property in and to the land under water lying west of the middle of the bar of New York, and west of the middle of that part of the Hudson River which lies between Manhattan Island and New Jersey.

2. The State of New Jersey shall have the exclusive jurisdiction of and over the wharves, docks, and improvements made and to be made on the shore of the said State; and of and over all vessels aground on said shore, or fastened to any such wharf or dock, except that the said vessels shall be subject to the quarantine or health laws, and laws in relation to passengers, of the State of New York, which now exist or which may hereafter be passed.

3. The State of New Jersey shall have the exclusive right of regulating the fisheries on the westerly side of the middle of said waters: *Provided*, That the navigation be not obstructed or hindered.

ARTICLE FOURTH. The State of New York shall have exclusive jurisdiction of and over the waters of the Kill Von Kull between Staten Island and New Jersey to the westernmost end off Shorter's Island in respect to such quarantine laws, and laws relating to passengers, as now exist or may hereafter be passed under the authority of that State, and for executing the same; and the said State shall also have exclusive jurisdiction, for the like purposes, of and over the waters of the sound from the westermost end of Shorter's Island to Woodbridge Creek, as to all vessels bound to any port in the said State of New York.

ARTICLE FIFTH. The State of New Jersey shall have and enjoy exclusive jurisdiction of and over all the waters of the sound between Staten Island and New Jersey lying south of Woodbridge Creek, and of and over all the waters of Raritan Bay lying westward of a line drawn from the light-house at Prince's Bay to the mouth of Mattavan Creek; subject to the following rights of property and of jurisdiction of the State of New York, that is to say:

1. The State of New York shall have the exclusive right of property in and to the land under water lying between the middle of the said waters and Staten Island.

2. The State of New York shall have the exclusive jurisdiction of and over the wharves, docks, and improvements made and to be made on the shore of Staten Island, and of and over all vessels aground on said shore, or fastened to any such wharf or dock; except that the said vessels shall be subject to the quarantine of health laws, and laws in relation to passengers of the State of New Jersey which now exist or which may hereafter be passed.

3. The State of New York shall have the exclusive right of regulating the fisheries between the shore of Staten Island and the middle of said waters: *Provided*, That the navigation of the said waters be not obstructed or hindered.

* * * * * * *

In 1876 commissioners were appointed to re-locate the land boundary between New York and New Jersey, and replace monuments that may have become dilapidated or removed, or to erect new ones, etc. (*Vide* Rev. of N. J., 1877.)

The above commissioners found in some cases a slight discrepancy between the original marks and the verbal description thereof, and the legislatures of each State ordered that the original monuments should be considered the true boundary. (*See* acts of New York, 1880, and acts of New Jersey, 1881.)

In the year 1774 commissioners were appointed by New York and Pennsylvania to fix the beginning of the 43d degree of north latitude

on the Mohawk or western branch of Delaware River, which is the northeast corner of Pennsylvania, and to proceed westward and fix the line between Pennsylvania and New York.

These commissioners reported in December of the same year that they fixed the said northeast corner of Pennsylvania, and marked it as follows, viz:

On a small island in the said river they planted a stone marked with the letters and figures, New York, 1774, cut on the north side thereof; and the letters and figures, latitude 42° variation 4° 20′, cut on the top thereof; and in a direction due west from thence on the west side of the said branch of Delaware, collected and placed a heap of stones at the water mark; and proceeding further west four perches, planted another stone in the said line marked with the letters and figures, Pennsylvania, 1774, cut on the south side thereof, and the letters and figures, latitude 42° variation 4° 20′, cut on the top thereof, and at the distance of eighteen perches due west from the last-mentioned stone marked an ash tree. The rigor of the season prevented them running the line farther.

Nothing further seems to have been done until 1786–'7, when commissioners were appointed to finish the work thus begun (*see* Cary & Biorden's Laws of Pennsylvania, Vol. III, page 392), and the lines were run and monuments erected. The line was ratified in 1789, and is as follows, viz:

Beginning at a point in Lake Erie, where the boundary line between the United States and Great Britain is intersected by a meridian line drawn through the most westerly bent or inclination of Lake Ontario; then south along said meridian line to a monument in the beginning of the forty-third degree of north latitude, erected in the year one thousand seven hundred and eighty-seven, by Abraham Herdenbergh and William W. Morris, commissioners on the part of this State, and Andrew Ellicott and Andrew Porter, commissioners on the part of the State of Pennsylvania, for the purpose of marking the termination of the line of jurisdiction between this State and the said State of Pennsylvania; then east along the line established and marked by said last-mentioned commissioners to the ninetieth mile-stone in the same parallel of latitude, erected in the year one thousand seven hundred and eighty-six, by James Clinton and Simeon DeWitt, commissioners on the part of this State, and Andrew Ellicott, commissioner on the part of Pennsylvania; which said ninetieth mile-stone stands on the western side of the south branch of the Tioga River; then east along the line established and marked by said last-mentioned commissioners, to a stone erected in the year one thousand seven hundred and seventy-four, on a small island in the Delaware River, by Samuel Holland and David Rittenhouse, commissioners on the part of the colonies of Pennsylvania and New York, for the purpose of marking the beginning of the forty-third degree of north latitude; then down along said Delaware River to a point opposite to the fork or branch formed by the junction of the stream called Mahackamack with the said Delaware River, in the latitude of forty-one degrees, twenty-one minutes and thirty-seven seconds north; then in a straight line to the termination on the east bank of the Delaware River of a line run in the year one thousand seven hundred and seventy-four, by William Wickham and Samuel Gale, commissioners on the part of the then colony of New York, and John Stevens and Walter Rutherford, commissioners on the part of the then colony of New Jersey. (*See* Revised Statutes of New York, 1881.)

The meridian line forming the western boundary of New York was surveyed and mapped in 1790 by Andrew Ellicott, as United States commissioner (Pa. Archives, Vol. XII—Map), and the latitude formerly

inscribed on the monument on Lake Erie, fixing the western boundary, was 42° 16′ 13″. The report of the commissioner has not been found.

In 1865 Dr. Peters, director of Hamilton College Observatory, under the directions of the Regents of the University of New York, determined the latitude and longitude of the boundary monument aforesaid, with the following result: Latitude, 42° 16′ 2″.8; longitude, 79° 45′ 54″.4. (*Vide* Dr. Peters' Report, 1868.)

In 1877 the parallel of the forty-second degree north latitude was ascertained at four points, by the New York and Pennsylvania Joint Boundary Commission, with the following result, viz:

1. At Travis Station (Hale's Eddy), very near the east end of that part of the New York and Pennsylvania line supposed to be on the forty-second parallel, the old line was found to be 275 feet north of the parallel.

2. At Finn's Station, about 20 miles from east end (Great Bend), the line is 350 feet south of the parallel.

3. At Burt's Station, about 70 miles from east end (Wellsburg), the line is 760 feet north of the parallel.

4. At Clark's Station, about 253 miles from east end (Wattsburg), the line is 150 feet north of the parallel.

(See pamphlet, Report of Penn. Board of the Penn. & N. Y. Joint Boundary Comm.)

## NEW JERSEY.

Although the original grants from the French and English sovereigns of 1603 and 1606 covered the territory forming the present State of New Jersey, the grant which first directly relates to New Jersey is that given in 1664 by the Duke of York to Lord John Berkeley and Sir George Carteret, two months before the setting out of his expedition to take possession of New York.

The following extract from that grant defines the boundaries, viz:

> All that tract of land adjacent to New England, and lying and being to the westward of Long Island and Manhitas Island, and bounded on the east part by the main sea and part by Hudson's River, and hath upon the west Delaware Bay or river, and extendeth southward to the main ocean as far as Cape May, at the mouth of Delaware Bay, and to the northward as far as the northernmost branch of the said bay or river of Delaware, which is forty-one degrees and forty minutes of latitude, and crosseth over thence in a strait line to Hudson's River in forty-one degrees of latitude; which said tract of land is hereafter to be called by the name or names of New Cesserea or New Jersey. (*Vide* Grants, Concessions, etc., of New Jersey, Leaming & Spicer, p. 8.)

In March, 1673, Lord Berkeley sold his undivided moiety of New Jersey to John Fenwick, by whom, in the following year, it was again sold. July 1, 1676, was executed the famous "Quintipartite deed," by which

the eastern part was given to Sir George Carteret, to be called East New Jersey, and the western part to the other proprietors, to be called West New Jersey. Sir George Carteret, at his death in 1678, left his land to be sold. It was sold in 1682 to the twelve proprietors, who admitted other partners.

Confirmation grants were made to the proprietors of both provinces by the Duke of York, and confirmed by the King, but between 1697 and 1701 the proprietors repeatedly made petitions to be allowed to surrender their right of government to the Crown. Accordingly, in 1702, the surrender was made and accepted by the Queen, and both parts united were made the province of New Jersey. (*Vide* Leaming and Spicer's grants, etc.)

(For the history of the northern and eastern boundary, *vide* New York, p. 73.)

The grant from the Duke of York to Berkeley and Carteret defined the west boundary of New Jersey to be the Delaware River. (*Vide* p. 76.)

The line between New Jersey and Delaware is thus described in the Revised Statutes of Delaware, p. 2, viz:

> Low-water mark on the eastern side of the river Delaware, within the twelve-mile circle from New Castle and the middle of the bay, below said circle.

In 1876 the legislature of New Jersey authorized the governor to commence a suit in the Supreme Court of the United States to settle the boundary between New Jersey and Delaware. New Jersey claimed jurisdiction to the middle of the Delaware, so far as the river and bay is a boundary between the two States. (*Vide* Revision of New Jersey, p. 1185.)

In 1783 Commissioners were appointed by New Jersey and Pennsylvania to settle the jurisdiction of the river Delaware and the islands within the same. Their report was ratified, and is in substance as follows:

First. It is declared that the river Delaware from the station point or northwest corner of New Jersey, northerly to the place upon the said river where the circular boundary of the State of Delaware touches upon the same, in the whole length and breadth thereof, is and shall continue to be and remain a common highway, equally free and open for the use, benefit, and advantage of the said contracting parties, etc.

Second. That each State shall enjoy and exercise a concurrent jurisdiction within and upon the water, and not upon the dry land between the shores of said river, etc.

Third. That all islets, islands, and dry land within the bed and between the shores of said river, and between said station point northerly and the falls of Trenton southerly, shall, as to jurisdiction, be hereafter deemed and considered as parts and parcels of the State to which such insulated dry land doth lie nearest at the time of making this agree-

ment, and that from said falls of Trenton to the State of Delaware southerly, certain islands (in the agreement they are named B) be annexed to each State respectively. (*Vide* Revision of New Jersey, p. 1181.)

In 1786 commissioners were appointed by New Jersey and Pennsylvania for more accurately determining and describing the islands mentioned in the foregoing agreement; that is, those in the Delaware from the northwest corner of New Jersey down to the falls of Trenton. Their report was ratified, and a long list of islands, described by name in the act, were annexed to each State respectively. (*Vide* Revision of New Jersey, pp. 1182–'3.)

## PENNSYLVANIA.

The Swedish West India Company, chartered by the King of Sweden in 1625, established the first permanent settlement on the west bank of the Delaware, occupying a part of the territory now in Pennsylvania and Delaware, although the Dutch had previously established trading posts, which had been destroyed by the Indians. The Swedes acquired, by successive purchases from the Indian chiefs, all the land extending from Cape Henlopen to the great falls of the Delaware, calling it New Sweden. (*Vide* C. and C., p. 1509.)

In 1655 this territory was surrendered to the Dutch. (*Vide* Hazard's Annals of Pennsylvania, p. 185.)

By the conquest of the New Netherlands, in 1664, the Duke of York seems to have successfully claimed the settlements on the west bank of the Delaware as a part of his dominions.

In 1681 Charles II of England granted to William Penn the Province of Pennsylvania. The following extract from the charter defines the boundaries:

* * * all that Tracte or Parte of Land in America, with all the Islands therein conteyned, as the same is bounded on the East by Delaware River, from twelve miles distance Northwards of New Castle Towne unto the three and fortieth degree of Northerne Latitude, if the said River doeth extende so farre northwards; But if the said River shall not extend soe farre Northward, then by the said River soe farr as it doth extend; and from the head of the said River the Eastern Bounds are to bee determined by a Meridian Line, to bee drawne from the head of the said River, unto the said three and fortieth degree. The said Lands to extend westwards five degrees in longitude, to bee computed from the said Easterne Bounds; and the said Lands to bee bounded on the North by the beginning of the three and fortieth degree of Northern Latitude, and on the South by a Circle drawne at twelve miles distance from New Castle Northward and Westward unto the beginning of the fortieth degree of Northern Latitude, and thence by a streight Line Westward to the Limit of Longitude above mentioned.

William Penn, in order to perfect his title, procured of the Duke of York a deed bearing date August 21, 1682, by which the Duke of York conveyed to him all title and claim which he might have to the province of Pennsylvania. (*Vide* Hazard's Annals of Pa., 586 *et seq.*)

He also purchased of the Duke of York the territory now comprising the State of Delaware, which he held until 1701–'2, when he granted a charter which enabled them to set up a separate government, though still under proprietory control. (*Vide* C. and C., p. 270 *et seq.*)

(For a history of the northern and eastern boundaries of Pennsylvania, see New York and New Jersey, pp. 71 and 76.]

That part of the southern boundary of Pennsylvania between Pennsylvania and Delaware is an arc of a circle, having for its center the steeple of the old court-house at New Castle, Del., and a radius of 12 miles. This was surveyed and marked under a warrant from William Penn in 1701. (*Vide* Hazard's Annals of Pennsylvania.)

This circular line, in connection with adjacent lines, was made the subject of controversy for many years.

According to the original grants of Pennsylvania and Maryland the boundary between them was to be the fortieth degree of north latitude.

This line being found to pass north of Philadelphia and to exclude Pennsylvania from Delaware Bay, negotiations ensued between the proprietors to rectify this geographical blunder, and for nearly a century the matter remained unsettled.

In the year 1732 an agreement was made to fix the boundary. Commissioners were appointed in that year, and subsequently in 1739, to run the line, but they failed to agree, and chancery suits were the result. Taking a decision of Lord Chancellor Hardwick in 1750 as a basis of final adjudication, an agreement was signed July 4, 1760. By this agreement the line between Pennsylvania and Delaware on the one part and Maryland on the other was determined as follows, viz:

A due east and west line should be run across the peninsula from Cape Henlopen to the Chesapeake Bay. From the exact middle of this line should be drawn a line tangent to the western periphery of a circle, having a radius of 12 English statute miles, measured horizontally from the center of the town of New Castle. From the tangent point a line should be drawn due north until it cut a parallel of latitude 15 miles due south of the most southern part of the city of Philadelphia, this point of intersection to be the northeast corner of Maryland; thence the line should run due west on said parallel as far as it formed a boundary between the two governments. (*Vide* Delaware, p. 81.)

In 1760 commissioners and surveyors were appointed, who spent three years in measuring the base line and the tangent line between Maryland and Delaware.

The proprietors then, wearied with the delay, sent over from England two famous mathematicians, Charles Dixon and Jeremiah Mason, who verified the work of their predecessors, and ran the line west between Pennsylvania and Maryland, since known as "Mason and Dixon's line."

Mason and Dixon fixed the latitude of this line at 39° 43′ 18″. A resurvey in 1850 by Colonel Graham determined it to be 39° 43′ 26″.3.

Mason and Dixon begun their work in 1763, and were stopped by Indians in 1767, having run the line about 244 miles west of the Delaware, not quite finishing their work. They put up mile stones all along said line, every fifth one being marked with the arms of the respective proprietors.

In consequence of the accidental removal of the stone at the northeast corner of Maryland, commissioners were appointed in 1850 by Pennsylvania, Delaware, and Maryland to revise the former survey, which was done by Lieutenant-Colonel Graham, of the United States topographical engineers. The result confirmed the work of Mason and Dixon, and Maryland gained by the resurvey a little less than two acres.

(For a full report of the running of Mason and Dixon's line in 1763–'67, and the verification by Colonel Graham in 1850, see Senate Journal of Delaware for 1851, pages 56–109.)

In 1784 the report of the commissioners who had been appointed to fix the boundaries between Virginia and Pennsylvania (West Virginia then forming part of Virginia) was confirmed, and the lines so fixed are as follows, viz:

The line commonly called Mason and Dixon's line to be extended due west five degrees of longitude from the river Delaware, for the southern boundary of Pennsylvania, and a meridian drawn from the western extremity thereof to the northern limits of the said States, respectively, be the western boundary of Pennsylvania. (*Vide* C. and B. laws of Pennsylvania, Vol. II, p. 495, and Hening's Virginia, Vol. XI, p. 554.)

By the cession of 1784, by Virginia to the United States—and that of 1800, by Connecticut to the United States, and the formation of the State of West Virginia from a portion of Virginia in 1862—the abovementioned meridian line becomes the boundary between Pennsylvania on the east, and Ohio and West Virginia on the west.

By an examination of the cession of 1781, by New York to the United States, it will be seen that a small triangular tract on Lake Erie was left in the hands of the General Government. This was sold to Pennsylvania in 1792.

## DELAWARE.

The State of Delaware was originally settled by the Swedes. (*Vide* Pennsylvania, p. 78.) In 1655 it was surrendered to the Dutch, who, in 1664, in turn surrendered it to the English, and it was taken possession of by the Duke of York.

William Penn, having received in 1682 a grant of the province of Pennsylvania, bought of the Duke of York the territory comprising the present State of Delaware. It was conveyed to him by two deeds

of feoffment, dated August 24, 1682, one conveying the town of New Castle and a twelve-mile circle around the same, and the other conveying all the lands south of said circle to Cape Henlopen. (See Hazard's Annals of Pennsylvania, p. 588, *et seq.*)

Soon after the grant made by the royal charter aforesaid, an assembly of the province and three lower counties (then called the territories) was called by the proprietary and governor aforesaid, which met at Chester on the seventh day of December, 1682, when the following laws, among others, were passed, to wit:

* * * Since * * * it has pleased King Charles the Second * * * to grant * * * William Penn, esq., * * * this Province of Pennsylvania * * * And * James Duke of York and Albany * * * to release his right and claim * * * to the Province of Pennsylvania * * * and * * * to grant unto the said William Penn * * * all that tract of land from twelve miles northward of New Castle, on the river Delaware, down to the South Cape (commonly called Cape Henlopen, and by the Proprietary and Governor now called Cape Jomus) lying on the west side of the said river and bay, * * * lately cast into three counties, called New Castle, Jones, and Whorekills (alias New Dale. * * * Be it enacted * * that the counties of New Castle, Jones, and Whorekills alias New Dale * * * are annexed to the Province of Pennsylvania. * * * (Dallas' Laws of Pennsylvania, 1797, Vol. I, Appendix, p. 24, *et seq*).

In 1701 William Penn granted a charter, under which the province of Pennsylvania and the territories (as Delaware was then called) were made separate governments, though both were still under the proprietary government of William Penn. (C. & C., p. 270.)

By the Revolution the "territories" became the State of Delaware, with substantially her present boundaries.

(For a history of the boundaries between Delaware and Pennsylvania, *vide* Pennsylvania, p. 79, and between Delaware and New Jersey, *vide* New Jersey, p. 77, *et seq.*)

From 1732 to 1769 there was a controversy between the proprietors of Pennsylvania and Maryland in regard to boundaries (*vide* p. 79). The boundaries of Delaware on the north and west—Delaware then being under the jurisdiction of Pennsylvania—were determined as follows, viz:

Beginning at Cape Henlopen and running due west 34 miles 309 perches; thence in a straight line 81 miles 78 chains and 30 links up the peninsula until it touches and makes a tangent to the western periphery of a circle, drawn at the horizontal distance of twelve English statute miles from the center of the town of New Castle.

From this tangent point a line was run due north till it cut a parallel of latitude 15 miles due south of the most southern part of the city of Philadelphia. This point of intersection is the northeast corner of Maryland. The tangent line bearing a little west of north, the due north line from the tangent point cuts off an arc of the 12-mile circle. The boundary line follows the arc of the circle from the tangent point around to the point where the due north line intersects the 12-mile

circle, then follows said due north line to said northeast corner of Maryland. The length of said due north line is 5 miles 1 chain and 50 links, as given by Mason and Dixon. (*Vide* Jour. Del. Sen., 1851, p. 56 *et seq.*)

By the agreement of 1760, based on the decree of Chancellor Hardwick, a due east and west line should be run across the peninsula from Cape Henlopen to Chesapeake Bay, etc. The decree of Lord Hardwick says, touching the position of Cape Henlopen, "that Cape Henlopen ought to be deemed and taken to be situated at the place where the same is laid down and described in the map or plan annexed to the said articles to be situated, and therefore his lordship doth further order and decree that the said articles be carried into execution accordingly," etc.

In Hazard's Annals of Pennsylvania, p. 5, is found the following, viz: "The cape now called Henlopen was then called Cornelis."

William Penn directed that Cape Henlopen be called Cape James. (*Vide* Hazard's Pennnsylvania, p. 606; also *vide* Act of union of the territories to Pennsylvania.)

The foregoing statements explain the seeming incongruity between the base line across the peninsula and the position of Cape Henlopen as laid down on all modern maps.

## MARYLAND.

The territory comprising the present area of Maryland was included in the previous charters of Virginia, notwithstanding which, in the year 1632, Lord Baltimore received a royal grant of the province of Maryland, whose boundaries are defined in the following extract:

All that part of the Peninsula or Chersonese, lying in parts of America, between the ocean on the east and the Bay of Chesapeake on the west; divided from the residue thereof by a right line drawn from the promontory or headland called Watkins Point, situate upon the bay aforesaid, near the River Wighco on the west unto the main ocean on the east, and between that boundary on the south unto that part of the Bay of Delaware on the north, which lieth under the fortieth degree of north latitude from the equinoctial, where New England is terminated; and all the tract of that land within the metes underwritten (that is to say), passing from the said bay, called Delaware Bay, in a right line, by the degree aforesaid, unto the true meridian of the first fountain of the River Pattowmack; thence verging towards the south unto the farther bank of the said river, and following the same on the west and south unto a certain place called Cinquack, situate near the mouth of said river, where it disembogues into the aforesaid Bay of Chesapeake, and thence by the shortest line unto the aforesaid promontory or place called Watkins Point, so that the whole tract of land divided by the line aforesaid, between the main ocean and Watkins Point unto the promontory called Cape Charles, may entirely remain forever excepted to us * * * * * * *.

By an examination of the limits laid down in this charter, and a comparison with the several charters of Virginia and the charter and deeds

to William Penn, it will be seen that there was a conflict of boundaries on both sides of the Maryland grant.

The history of the long controversy with Pennsylvania has already been given (*vide* Pennsylvania, p. 79, and Delaware, p. 80). Virginia on the south claimed the territory under her charters, and for a time seemed disposed to assert her claim, notwithstanding we find in 1638 a proclamation by the governor and council of Virginia recognizing the province of Maryland, and forbidding trade with the Indians within the limits of Maryland without the consent of Lord Baltimore previously obtained (*vide* Bozman's Maryland, vol. II, p. 586). Virginia's claim was finally given up by a treaty or agreement made in 1658. (For a full account *vide* Bozman's Maryland, p. 444 *et seq.*)

In 1663 the Virginia assembly ordered a survey of the line between Virginia and Maryland on the peninsula, and declared it to be as follows, viz:

From Watkins Point east across the peninsula.

They define Watkins Point

To be the north side of Wicomicoe River on the Eastern shore and neere unto and on the south side of the streight limbe oppoeite to Patuxent River.

(*Vide* Hening's Virginia, vol. II, p. 184.)

In 1668 commissioners were appointed by Maryland and Virginia to fix the boundary across the peninsula. The commissioners were Philip Calvert, esq., chancellor of Maryland, and Col. Edmund Scarbrugh, his majesty's surveyor-general of Virginia. Their report is as follows, viz:

* * * After a full and perfect view taken of the point of land made by the north side of Pocomoke Bay and south side of Annamessexs Bay have and do conclude the same to be Watkins Point, from which said point so called, we have run an east line, agreeable with the extreamest part of the westermost angle of the said Watkins Point, over Pocomoke River to the land near Robert Holston's, and there have marked certain trees which are so continued by an east line running over Swansecutes Creeke into the marsh of the seaside with apparent marks and boundaries * * * Signed June 25, 1668. (*Vide* Md. Hist. Soc. Coll. of State papers, volume marked 4 L. C. B., pp. 63–64.)

Virginia, by the adoption of her constitution of 1776 (see Article 21), relinquished all claim to territory covered by the charter of Maryland, thereby fixing Maryland's western boundary as follows:

Commencing on a true meridian of the first fountain of the river Pattawmack, thence verging towards the south unto the further bank of the said river and following the same on the west and south unto a certain place called Cinquack, situate near the mouth of said river where it disembogues into the aforesaid bay of Chessopeake, and thence by the shortest line unto the aforesaid promontory or place called Watkins Point, thence a right line to the main ocean on the east. (See charter of Maryland.)

The foregoing are substantially the present boundaries; but from that time up to the present a controversy has been going on concerning them.

In 1786 a compact was entered into between the States of Maryland and Virginia, but as this referred more particularly to the navigation

and exercise of jurisdiction on the waters of Chesapeake Bay, the Potomac and Pocomoke Rivers, they are not given here. (*Vide* Hening's Va., Vol. XII, p. 50.)

From 1821 to 1858 frequent legislation took place in regard to this boundary.

In the last-named year commissioners were appointed by Maryland and Virginia, respectively, who, with the assistance of Lieut. N. Michler, United States Engineers, surveyed the lines.

In 1860 the governor of Virginia, under a resolution of the legislature, appointed and sent an agent to England to collect records and documentary evidence bearing on this question.

The rebellion ensuing, nothing further was done until 1867, when legislation again commenced.

The question of this boundary was referred to arbitrators by an agreement made in 1874, each State binding itself to accept their award as final and conclusive.

J. S. Black, of Pennsylvania; William A. Graham, of North Carolina, and Charles A. Jenkins, of Georgia, were appointed arbitrators.

William A. Graham having died, James B. Beck, of Kentucky, was appointed in his stead.

The arbitrators made, in 1877, the following award, viz:

Beginning at the point on the Potomac River where the line between Virginia and West Virginia strikes the said river at low-water mark, and thence following the meanderings of said river by the low-water mark to Smith's Point, at or near the mouth of the Potomac, in the latitude 37° 53′ 8″ and longitude 76° 13′ 46″; thence crossing the waters of the Chesapeake Bay, by a line running north 65° 30′ east, about nine and a half nautical miles to a point on the western shore of Smith's Island at the north end of Sassafras Hammock, in latitude 37° 57′ 13″, longitude 76° 2′ 52″; thence across Smith's Island south 88° 30′ east five thousand six hundred and twenty yards to the center of Horse Hammock, on the eastern shore of Smith's Island, in latitude 37° 57′ 8″, longitude 75° 59′ 20″; thence south 79° 30′ east four thousand eight hundred and eighty yards to a point marked "A" on the accompanying map, in the middle of Tangier Sound, in latitude 37° 56′ 42″, longitude 75° 56′ 23″, said point bearing from James Island light south 54° west, and distant from that light three thousand five hundred and sixty yards; thence south 10° 30′ west four thousand seven hundred and forty yards by a line dividing the waters of Tangier Sound, to a point where it intersects the straight line from Smith's Point to Watkins Point, said point of intersection being in latitude 37° 54′ 21″, longitude 75° 56′ 55″, bearing from James Island light south 29° west and from Horse Hammock south 34° 30′ east. This point of intersection is marked "B" on the accompanying map. Thence north 85° 15′ east six thousand seven hundred and twenty yards along the line above mentioned, which runs from Smith's Point to Watkins Point until it reaches the latter spot, namely Watkins Point, which is in latitude 37° 54′ 38″, longitude 75° 52′ 44″. From Watkins Point the boundary line runs due east seven thousand eight hundred and eighty yards to a point where it meets a line running through the middle of Pocomoke Sound, which is marked "C" on the accompanying map, and is in latitude 37° 54′ 38″, longitude 75° 47′ 50″; thence by a line dividing the waters of Pocomoke Sound north 47° 30′ east five thousand two hundred and twenty yards to a point in said sound marked "D" on the accompanying map, in latitude 37° 56′ 25″, longitude 75° 45′ 26″; thence following the middle

of Pocomoke River by a line of irregular curves, as laid down on the accompanying map, until it intersects the westward protraction of the boundary line marked by Scarborough and Calvert, May 28, 1668, at a point in the middle of Pocomoke River, and in the latitude 37° 59′ 37″, longitude 75° 37′ 4″; thence by the Scarborough and Calvert line, which runs 5° 15′ north of east, to the Atlantic Ocean.

The latitudes, longitudes, courses, and distances here given have been measured upon the Coast Chart No. 33 of U. S. Coast Survey, sheet No. 3, Chesapeake Bay. * * * The middle thread of the Pocomoke River and the low-water mark on the Potomac River are to be measured from headland to headland, without considering or following arms, inlets, creeks, bays, or affluent rivers. * * * (*Vide* U. S. Stat. at Large, Vol. XX, p. 481.)

This award was ratified by the States of Maryland and Virginia, and confirmed by Congress in 1879.

In 1879–'80 acts were passed by the legislatures of Maryland and Virginia to appoint commissioners and to request the General Government to designate one or more officers of the Engineer Corps, said commissioners and officers to survey and mark said line and erect monuments thereon.

West Virginia having been formed from a part of Virginia and admitted into the Union in 1862, the western boundary of Maryland now separates it from the State of West Virginia.

The commissioners appointed in 1859 by Virginia and Maryland (*vide* p. 84) surveyed the western boundary from the "Fairfax Stone" (the first fountain of the Potomac) due north to the Pennsylvania line, and the legislature of Maryland in 1860 passed an act declaring that line to to be its western boundary.

From the "Fairfax Stone" the boundary between Maryland and West Virginia runs along the south bank of the Potomac River till it strikes the line between Virginia and West Virginia.

(For a history of the placing of the Fairfax Stone, *vide* Virginia, p. 90.)

## DISTRICT OF COLUMBIA.

On the 5th day of September, 1774, the Continental Congress met at Philadelphia. Two years later they adjourned to Baltimore. During the Revolution and subsequent to the treaty of peace they met in various places. After the close of the war much debate took place in regard to the location of a permanent seat of the Government of the United States. Several States made propositions to Congress, offering to cede certain lands for the purpose, but no determination of the location was made by Congress until 1790.

*Act of cession from the State of Maryland, passed December* 23, 1788.

On the 23d of December, 1788, the State of Maryland passed the following act, viz:

*Be it enacted by the general assembly of Maryland*, That the representatives of this

State in the House of Representatives of the Congress of the United States, appointed to assemble at New York, on the first Wednesday of March next, be and they are hereby authorized and required on the behalf of this State to cede to the Congress of the United States, any district in this State not exceeding ten miles square, which the Congress may fix upon and accept for the seat of government of the United States.

**In the following year (December 3, 1789), the State of Virginia passed a similar act, of which the following is an extract:**

*Be it therefore enacted by the general assembly*, That a tract of country not exceeding ten miles square or any lesser quantity, to be located within the limits of the State, and in any part thereof as Congress may by law direct shall be, and the same is hereby, *forever* ceded and relinquished to the Congress and Government of the United States, in full and absolute right and exclusive jurisdiction, as well of said soil as of persons residing or to reside thereon, pursuant to the tenor and effect of the eighth section of the 1st article of the Constitution of the Government of the United States.

**After long discussion, Congress in 1790, in view of the foregoing cessions of Maryland and Virginia, passed the following act, viz:**

AN ACT for establishing the temporary and permanent seat of government of the United States. Approved July 16, 1790.

SECT. 1. *Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled*, That a district of territory, not exceeding ten miles square, to be located as hereafter directed on the river Potowmac, at some place between the mouth of the Eastern Branch and Connoyocheque, be, and the same is hereby, accepted for the permanent seat of the government of the United States. *Provided nevertheless*, That the operation of the laws of the State within such district shall not be affected by this acceptance until the time fixed for the removal of the government thereto, and until Congress shall otherwise by law provide.

SECT. 2. *And be it further enacted*, That the President of the United States be authorized to appoint, and by supplying vacancies happening from refusals to act or other causes, to keep in appointment as long as may be necessary, three commissioners, who, or any two of whom, shall, under the direction of the President, survey, and by proper metes and bounds define and limit, a district of territory, under the limitations above mentioned; and the district so defined, limited, and located shall be deemed the district accepted by this act for the permanent seat of the government of the United States.

SECT. 3. *And be it enacted*, That the said commissioners, or any two of them, shall have power to purchase or accept such quantity of land on the eastern side of the said river within the said district as the President shall deem proper for the use of the United States, and according to such plans as the President shall approve. The said commissioners, or any two of them, shall, prior to the first Monday in December in the year 1800, provide suitable buildings for the accommodation of Congress, and of the President, and for the public offices of the government of the United States.

SECT. 4. *And be it enacted*, That for defraying the expenses of such purchases and buildings the President of the United States be authorized and requested to accept grants of money.

SECT. 5. *And be it enacted*, That prior to the first Monday in December next all offices attached to the seat of government of the United States shall be removed to, and until the first Monday in December in the year 1800 shall remain at, the city of Philadelphia, in the State of Pennsylvania, at which place the session of Congress next ensuing the present shall be held.

SECT. 6. *And be it enacted*, That on the first Monday in December, in the year 1800, the seat of the government of the United States, shall, by virtue of this act, be transferred to the district and place aforesaid. And all offices attached to the said seat of government shall accordingly be removed thereto by their respective holders, and

shall, after the said day, cease to be exercised elsewhere, and that the necessary expense of said removal, shall be defrayed out of the duties on imposts and tonnage, of which a sufficient sum is hereby appropriated.

In the following year the foregoing act was amended, in order to include a portion of the Eastern Branch, and the town of Alexandria within the limits of the district.

The following is the act of amendment:

AN ACT to amend "An act for establishing the temporary and permanent seat of government of the United States." Approved March 3, 1791.

*Be it enacted, &c.*, That so much of the act entitled "An act for establishing the temporary and permanent seat of the government of the United States, as requires that the whole of the district of territory, not exceeding ten miles square, to be located on the river Potowmac, for the permanent seat of the government of the United States, shall be located above the mouth of the Eastern Branch, be and is hereby repealed, and that it shall be lawful, for the President to make any part of the territory below said limit and above the mouth of Hunting Creek, a part of the said district so as to include a convenient port of the Eastern Branch, and of the lands lying on the lower side thereof; and also the town of Alexandria, and the territory so to be included shall form a part of the district not exceeding ten miles square for the permanent seat of the government of the United States, in like manner, and to all intents and purposes, as if the same had been within the the purview of the above recited act: *Provided*, That nothing herein contained, shall authorize the erection of the public buildings, otherwise than on the Maryland side of the river Potowmac, as required by the aforesaid act.

In pursuance of the foregoing acts, three commissioners were appointed, who made preliminary surveys of the territory, and on the 30th day of March, 1791, George Washington, President of the United States, issued a proclamation, in which the bounds of the said District were defined as follows, viz:

Beginning at Jones' Point, being the upper cape of Hunting Creek, in Virginia, and at an angle in the outset of 45° west of the north, and running in a direct line ten miles for the first line; then beginning again at the same Jones' Point and running another direct line at a right angle with the first, across the Potomac, ten miles for the second line; then, from the terminations of the said first and second lines, running two other direct lines, of ten miles each, the one crossing the Potomac and the other the Eastern Branch aforesaid, and meeting each other in a point.

In 1800 Congress removed to this District. In the following year the District was divided into two counties, as follows, viz:

UNITED STATES STATUTES AT LARGE, SIXTH CONGRESS, SECOND SESSION, 1801, (CHAPTER XV).

AN ACT concerning the District of Columbia.

The said District of Columbia shall be formed into two counties. One county shall contain all that part of said District which lies on the east side of the river Potomac, together with the islands therein, and shall be called the county of Washington, the other county shall contain all that part of said District which lies on the west side of said river, and shall be called the county of Alexandria; and the said river, in its whole course through said District, shall be taken and deemed to all intents and purposes to be within both of said counties.

In 1846 Congress passed an act retroceding to the State of Virginia that part of the District of Columbia originally ceded to the United States by Virginia. The following is an extract from said act of retrocession:

That with assent of the people of the county and town of Alexandria, to be ascertained as hereinafter prescribed, all of that portion of the District of Columbia ceded to the United States by the State of Virginia, and all the rights and jurisdiction therewith ceded over the same, be, and the same are, hereby ceded and forever relinquished to the State of Virginia in full and absolute right and jurisdiction, as well of soil as of persons residing or to reside thereon.

## VIRGINIA.

In the year 1606 King James I of England granted the "First Charter of Virginia." The boundaries therein described are as follows, viz:

* * * Situate, lying, or being all along the sea coasts, between four and thirty degrees of northerly latitude from the equinoctial line, and five and forty degrees of the same latitude, and in the main land between the same four and thirty and five and forty degrees and the islands thereunto adjacent, or within one hundred miles of the coast thereof. * * *

Soon after, in 1609, a new charter was granted, called the "Second Charter of Virginia," which defines the boundaries in the following terms:

* * * Situate, lying, and being in that part of America called Virginia, from the point of land called Cape or Point Comfort, all along the sea coast to the northward two hundred miles, and from the said point of Cape Comfort all along the sea coast to the southward two hundred miles, and all that space and circuit of land lying from the sea coast of the precinct aforesaid up into the land, throughout from sea to sea, west and northwest, and also all the islands lying within one hundred miles along the coast of both seas of the precinct aforesaid. * * *

In 1611–'12 the "Third Charter of Virginia" was granted, which was an enlargement of the second, of which the following is an extract:

All and singular those islands whatsoever, situate and being in any part of the ocean seas bordering upon the coast of our said first colony in Virginia, and being within three hundred leagues of any of the portes heretofore granted to the said treasurer and company in our former letters-patents as aforesaid, and being within or between the one-and-fortieth and thirtieth degrees of northerly latitude.

These boundaries, as will be seen, included territory composing wholly, or in part, the present States of Pennsylvania, Delaware, Maryland, North and South Carolina, in addition to others formed since the Revolution.

This large extent of territory was reduced in the first instance by the charter of Maryland in 1632, next by the charters of Carolina in 1663 and 1665, then by the charter of Pennsylvania in 1681, and, again, subsequent to the Revolution, by the cession to the United States of the territory northwest of the Ohio River in 1784; by the admission of

Kentucky as an independent State in 1792, and lastly by the division of the territory of Virginia in 1862, by which the new State of West Virginia was created and admitted into the Union.

By the constitution of 1776 Virginia formally gave up all claim to the territory now appertaining to the neighboring States of Maryland, Pennsylvania, North and South Carolina.

The following is an extract from the Virginia constitution of 1776:

The territories contained within the charters erecting the colonies of Maryland, Pennsylvania, North and South Carolina, are hereby ceded, released, and forever confirmed to the people of these colonies, respectively, with all the rights of property, jurisdiction, and government, and all the rights whatsoever, which might at any time heretofore have been claimed by Virginia, except the free navigation and use of the rivers Potomaque and Pokomoke, with the property of the Virginia shores and strands bordering on either of said rivers, and all improvements which have been or shall be made thereon. The western and northern extent of Virginia shall, in all other respects, stand as fixed by the charter of King James I, in the year one thousand six hundred and nine, and by the public treaty of peace between the courts of Britain and France in the year one thousand seven hundred and sixty-three, unless by act of the legislature one or more governments be established westwards of the Alleghany Mountains.

In the mean time a grant of territory had been made, within the present limits of Virginia and West Virginia, which caused great dissatisfaction to the people of the Virginia Colony, and which ultimately had an important bearing in settling the divisional line between Maryland and Virginia.

In the 21st year of Charles II a grant was made to Lord Hapton and others of what is called the northern neck of Virginia, which was sold by the other patentees to Lord Culpeper and confirmed to him by letters-patent in the fourth year of James II. This grant carried with it nothing but the right of soil and incidents of ownership, it being expressly subjected to the jurisdiction of the government of Virginia. The tract of land thereby granted was "bounded by and within the heads of the rivers Tappahannock, alias Rappahannock, and Quiriough, alias Patomac, rivers." On the death of Lord Culpeper, this proprietary tract descended to Lord Fairfax, who had married Lord Culpeper's only daughter.

As early as 1729 difficulties sprung up, arising from conflicting grants from Lord Fairfax and the Crown.

In 1730 Virginia petitioned the King, reciting that the head springs of the Rappahannock and Potomac Rivers were not known, and praying that such measures might be taken that they might be ascertained to the satisfaction of all parties.

In 1733 Lord Fairfax made a similar petition, asking that a commission might issue for running out, marking, and ascertaining the true boundaries of his grant.

An order, accordingly, was issued and three commissioners were appointed on the part of the Crown and three on the part of Lord Fairfax.

The duty which devolved upon these commissioners was to ascertain by actual examination and survey the respective fountains of the Rappahannock and Potomac Rivers. This survey was made in 1736.

The report of the commissioners was referred to the council for plantation affairs in 1738, who reported their decision in 1745, as follows, viz:

* * * The said boundary ought to begin at the first spring of the south branch of the river Rappahannock, and that the said boundary be from thence drawn in a straight line northwest to the place in the Alleghany Mountains where that part of the Potomac River, which is now called Cohongoroota, first rises. * * *

This report was confirmed by the King, and commissioners were appointed to run and mark the dividing line accordingly.

The line was run in 1746. On the 17th day of October, 1746, they planted the Fairfax stone at the spot which had been described and marked by the preceding commissioners as the true head spring of the Potomac River, and which, notwithstanding much controversy, has continued to be regarded, from that period to the present time, as the southern point of the western boundary between Virginia and Maryland. (*Vide* Faulkner's Report to Governor of Virginia, 1832. For full details, *vide* Byrd Papers, 1866, Vol. II, p. 83 *et seq.* Also Hening's Va. Statutes.)

This tract of country was held by Lord Fairfax and his descendants many years, but subsequent to the Revolution the quitrents, charges, etc., were abolished and it became in all respects subject to the jurisdiction of Virginia.

(For the history of the settlement of the boundary lines between Virginia and Maryland, *vide* Maryland, p. 83.)

(For a history of the boundary between Virginia and Pennsylvania, *vide* Pennsylvania, p. 80.)

Kentucky formed originally a part of the county of Fincastle, Virginia. In the year 1776, this county was divided into three counties, the westernmost of which was called Kentucky County, and its eastern boundary was declared to be as follows, viz:

A line beginning on the Ohio, at the mouth of Great Sandy Creek, and running up the same and the main or northeasterly branch thereof to the Great Laurel Ridge or Cumberland Mountains; thence southwesterly along the said mountain to the line of North Carolina. (See Hening's Statutes, Virginia, Vol. 9, p. 257.)

Kentucky having been admitted into the Union June 1, 1792, commissioners were appointed in 1798 by Virginia and Kentucky to fix the boundary. In 1799–1800 the commissioners' report was made and ratified by the States. It was as follows, viz:

To begin at the point where the Carolina, now Tennessee, line crosses the top of the Cumberland Mountains, near Cumberland Gap, thence northeastwardly along the top or highest part of the said Cumberland Mountain, keeping between the head waters of Cumberland and Kentucky Rivers, on the west side thereof, and the head waters of Powell's and Guest's Rivers, and the Pond Fork of Sandy, on the east side therof, continuing along the said top, or highest part of said mountain, crossing the road

leading over the same at the Little Paint Gap, where by some it is called the Hollow Mountain and where it terminates at the West Fork of Sandy, commonly called Russell's Fork, thence with a line to be run north 45° east till it intersects the other great principal branch of Sandy, commonly called the Northeastwardly branch, thence down the said Northeastwardly branch to its junction with the main west branch and down Main Sandy to its confluence with the Ohio. (See Shepard's Virginia, Vol. 2, p. 234.)

It will be seen that the latter part of this line is the present line between West Virginia and Kentucky.

(For the history of the settlement of the boundaries between Virginia and North Carolina, *vide* North Carolina, *vide* p. 94.)

In 1779 Virginia and North Carolina appointed commissioners to run the boundary line between the two States west of the Alleghany Mountains, on the parallel of 36° 30′. The commissioners were unable to agree on the location of the parallel; they therefore ran two parallel lines two miles apart, the northern known as Henderson's, and claimed by North Carolina, the southern known as Walker's line, and claimed by Virginia. In the year 1789 North Carolina ceded to the United States all territory west of her present boundaries, and Tennessee being formed from said ceded territory, this question became one between Virginia and Tennessee.

Commissioners having been appointed by Virginia and Tennessee to establish the boundary, their report was adopted in 1803, and was as follows, viz:

A due west line equally distant from both Walker's and Henderson's, beginning on the summit of the mountain generally known as White Top Mountain, where the northeast corner of Tennessee terminates, to the top of the Cumberland Mountain, where the southwestern corner of Virginia terminates.

In 1871 Virginia passed an act to appoint commissioners to adjust this line.

Tennessee, the following year, in a very emphatic manner, passed a resolution refusing to reopen a question regarding a boundary which she considered "fixed and established beyond dispute forever." (See acts of Tennessee, 1872.)

Up to 1783 Virginia exercised jurisdiction over a large tract of country northwest of the Ohio River. But by a deed executed March 1, 1784, she ceded to the United States all territory lying northwest of the Ohio River, thus making her western boundary the west bank of the Ohio River.

On the 31st of December, 1862, the State of Virginia was divided, and 48 counties, composing the western part of the State, were made the new State of West Virginia. By an act of Congress in 1866, consent was given to the transfer of two additional counties from Virginia to West Virginia.

In 1873 and 1877 commissioners were appointed by each State to determine the true boundaries between the two States, and the General

Government was asked to detail officers of engineers to act with said commissioners in surveying and fixing the line.

Until their report is at hand, the boundary can only be found by following the old county lines. In view of the expectation of such report at an early day, it has not been thought best to go into an examination of the old county lines.

## WEST VIRGINIA.

This State was set off from Virginia on December 31, 1862. It was originally formed of those counties of Virginia which had refused to join in the secession movement. It was admitted to the Union as a separate State, June 19, 1863. It originally contained the following counties: Barbour, Boone, Braxton, Brooke, Cabell, Calhoun, Clay, Doddridge, Fayette, Gilmer, Greenbrier, Hampshire, Hancock, Hardy, Harrison, Jackson, Kanawha, Lewis, Logan, Marion, Marshall, Mason, McDowell, Mercer, Monongalia, Monroe, Morgan, Nicholas, Ohio, Pendleton, Pleasants, Pocahontas, Preston, Putnam, Raleigh, Randolph, Ritchie, Roane, Taylor, Tucker, Tyler, Upshur, Wayne, Webster, Wetzel, Wirt, Wood, Wyoming.

In 1866 it was enlarged by the two counties of Berkeley and Jefferson, transferred from Virginia. Its boundary with Virginia is made up of boundary lines of the border counties above enumerated; and can be defined only by reference to the laws by which these counties were created. In the constitution of 1872, after a recapitulation of the counties which were transferred from Virginia to West Virginia, is found the following clause defining the boundaries upon the south and west:

> The State of West Virginia includes the bed, bank, and shores of the Ohio River, and so much of the Big Sandy River as was formerly included in the Commonwealth of Virginia, and all territorial rights and property in and jurisdiction over the same heretofore reserved by and vested in the Commonwealth of Virginia, are vested in and shall hereafter be exercised by the State of West Virginia; and such parts of the said beds, banks, and shores as lie opposite and adjoining the several counties of this State shall form parts of said several counties respectively.

(For a history of the boundaries of West Virginia, *vide* Pennsylvania, p. 79; Maryland, p. 83; Virginia, p. 88.)

## NORTH CAROLINA.

In the year 1663 the "first charter of Carolina" was granted, which, two years later, in 1665, was enlarged by the "second charter of Carolina."

The following extracts from these two charters define the boundaries:

*Charter of Carolina*, 1663.

* * * All that territory or tract of ground, scituate, lying and being within our dominions of America, extending from the north end of the island called Lucke Island, which lieth in the Southern Virginia seas, and within six and thirty degrees of the northern latitude, and to the west as far as the south seas, and so southerly as far as the river Saint Matthias, which bordereth on the coast of Florida, and within one and thirty degrees of northern latitude, and so west in a direct line as far as the south seas aforesaid. * * *

*Charter of Carolina*, 1665.

* * * All that province, territory, or tract of land, scituate, lying or being in our dominions of America, aforesaid, extending north and eastward as far as the north end of Currituck River, or inlet, upon a strait westerly line to Wyonoke Creek, which lies within or about the degrees of thirty-six and thirty minutes, northern latitude, and so west in a direct line as far as the south seas. * * *

This is an extension of the charter of 1663, by which its northern boundary was removed from the approximate latitude of 36° to 36° 30′, on which parallel it is now approximately established. Although the exact year in which the division of the province of Carolina into the two provinces of North and South Carolina appears somewhat uncertain, I find it generally put down as 1729. The division line between the two provinces, North and South Carolina, appears to have been established by mutual agreement.

In the constitution of North Carolina of 1776 this line is defined as shown in the subjoined extract:

The property of the soil, in a free government, being one of the essential rights of the collective body of the people, it is necessary, in order to avoid future disputes, that the limits of the State should be ascertained with precision; and as the former temporary line between North and South Carolina was confirmed and extended by commissioners appointed by the legislatures of the two States, agreeable to the order of the late King George II in council, that line, and that only, should be esteemed the southern boundary of this State; that is to say, beginning on the sea side at a cedar stake, at or near the mouth of Little River (being the southern extremity of Brunswic County), and running from thence a northwest course through the boundary house, which stands in thirty-three degrees fifty-six minutes, to thirty-five degrees north latitude, and from thence a west course so far as is mentioned in the charter of King Charles II to the late proprietors of Carolina. Therefore, all the territory, seas, waters, and harbours, with their appurtenances, lying between the line above described, and the southern line of the State of Virginia, which begins on the sea shore, in thirty-six degrees thirty minutes north latitude, and from thence runs west, agreeable to the said charter of King Charles, are the right and property of the people of the State, to be held by them in sovereignty, any partial line, without the consent of the legislature of this State, at any time thereafter directed or laid out in anywise notwithstanding.

On December 2, 1789, the legislature passed an act ceding to the United States its western lands, now constituting the State of Tennessee. On February 25, 1790, the deed was offered, and on April 2 of the same year it was accepted by the United States.

In the Revised Statutes the north and south boundaries of the State are claimed to be as follows: The northern boundary, the parallel of 36° 30′; the southern boundary, a line running northwest from Goat Island on the coast in latitude 33° 56′ to the parallel of 35°, and thence along that parallel to Tennessee; while the western boundary is the Smoky Mountains. It is strange that the Revised Statutes should contain such a statement of the boundary lines when it is thoroughly well known that it is incorrect, especially as regards the southern boundary. In the case of the northern boundary the intention has been from the earliest colonial times down to the present to establish a line upon the parallel of 36° 30′. This is found to be the wording of every legislative act relating to it, and the errors of this boundary are due simply to errors in surveying and location. The following brief and comprehensive sketch of the north and south boundary lines of this State, and of the various attempts made to locate them, is taken from Professor Kerr's "Geology of North Carolina," vol. I, page 2:

"The first and only serious attempt to ascertain the northern boundary was that made in 1728, by Col. Wm. Byrd, and others, commissioners on the part of the two colonies, acting under Royal authority. From the account given by Byrd of this undertaking, it appears that they started from a point on the coast whose position they determined by observation to be in 36° 31′, north latitude, and ran due west (correcting for the variation of the compass), to Nottoway River, where they made an offset of a half mile to the mouth of that stream, again running west. The line was run and marked 242 miles from the coast, to a point in Stokes County, on the upper waters of the Dan River (on Peter's creek) the North Carolina commissioners accompanying the party only about two-thirds of the distance. Beyond this point, the line was carried some 90 miles by another joint commission of the two colonies in 1749; this survey, terminating at Steep Rock Creek, on the east of Stone Mountain, and near the present northwest corner of the State, was estimated to be 329 miles from the coast. In 1779 the line was taken up again at a point on Steep Rock Creek, determined by observation to be on the parallel of 36° 30′ (the marks of the previous survey having disappeared entirely), and carried west to and beyond Bristol, Tennessee. This last is known as the Walker line, from one of the commissioners of Virginia.

These lines were run and the latitude observations taken with very imperfect instruments, and the variation of the compass was little understood, so that it was not possible to trace a parallel of latitude. The line, besides, was only marked on the trees and soon disappeared, and as the settlements were very scattered the location soon became a matter of vague tradition and presently of contention and litigation, so that in 1858, at the instance of Virginia, commissioners were appointed to relocate the line from the end of the Byrd survey westward, but for some reason they did not act. In 1870 commissioners were again appointed by Virginia and similar action asked on the part of this State; and the proposition was renewed in 1871, but ineffectually, as before. In all these numerous attempts to establish the line of division between the two colonies and States, the intention and the specific instructions have been to ascertain and mark, as the boundary of the two States, *the parallel of* 36° 30′. The maps published towards the end of last century by Jefferson and others give that parallel as the line, and the bill of rights of North Carolina claims that "all the territory lying between the line above described (the line between North and South Carolina) and the southern line of the State of Virginia, which begins on the sea shore in 36° 30′ north latitude, and from thence runs west, agreeably to the

charter of King Charles, are the right and property of this State." But it appears from the operations of the United States Coast Survey at both ends of the line that the point of beginning on Currituck Inlet, instead of being, as so constantly assumed, in latitude 36° 30′, or as determined by the surveyors in 1728, 36° 31′ is 36° 33′ 15″, and the western end (of "the Walker line," of 1779, at Bristol, Tenn.) 36° 34′ 25.5″. It is stated in Byrd's Journal that the variation of the compass was ascertained to be a little less than 3° W. [The magnetic chart of the United States Coast Survey would make it 3° E.] And no account is given of any subsequent correction, and if none was made at the end of the line surveyed by him the course would have been in error by nearly 3°, as the amount of variation in this State changes a little more than 1° for every 100 miles of easting or westing. So that the northern boundary of the State as run is not only not the parallel of 36° 30′, but is far from coincident with any parallel of latitude, and must be a succession of curves, with their concavities northward and connected at their ends by north and south offsets.

The southern boundary between this State and South Carolina and Georgia was first established by a joint colonial commission in 1735 to 1746. The commissioners run a line from Goat Island on the coast (in latitude 33° 56′ as supposed) NW to the parallel of 35°, according to their observations, and then due west to within a few miles of the Catawba River, and here, at the old Salisbury and Charleston road, turned north along that road to the southeast corner of the Catawba Indian Lands. This line, resurveyed in 1764, was afterwards (in 1772) continued along the eastern and northern boundaries of the Catawba lands to the point where the latter intersects the Catawba River; thence along and up that river to the mouth of the South Fork of the Catawba, and thence due west, as supposed, to a point near the Blue Ridge. This part of the line was resurveyed and confirmed by commissioners under acts of assembly of 1803, 1804, 1806, 1813, 1814, and 1815, and continued west to and along the Saluda Mountains and the Blue Ridge to the intersection of the "Cherokee boundary" of 1797, and thence in a direct line to the Chatooga River at its intersection with the parallel of 35°. From this point the line was run west to the Tennessee line, between this State and Georgia, in 1807, and confirmed and established by act of 1819.

The boundary between this State and Tennessee was run, according to the course designated in the act of 1789, entitled "An act for the purpose of ceding to the United States certain western lands therein described" (the State of Tennessee); that is, along the crest of the Smoky Mountains, from the Virginia line to the Cataluche River (in Haywood County), in 1799, under act of 1796. It was continued from this point to the Georgia line in 1821. The commissioners who completed this line, at the date last-mentioned, instead of following their instructions, diverged from the crest of the Smoky (Unaka) Mountains at the intersection of the Hiwassee turnpike, and run *due south* to the Georgia line, thereby losing for the State the valuable mining region since known as Ducktown.

And as to the southern boundary, the point of beginning on Goat Island is in latitude 33° 51′ 37″, as shown by the Coast Survey, and instead of running from Goat Island northwest to latitude of 35° and thence along that parallel, it appears, from the South Carolina Geographical State Survey of 1821–'25, that the course from the starting point is N. 47° 30′ W., and instead of pursuing the parallel of 35° it turns west about 10 miles south of that line, and then on approaching the Catawba River, turns northward pursuing a zigzag line to the forks of the Catawba River, which is about 12 miles north of that parallel; and from this point to the mountains the boundary line (of 1772) runs, not west, but N. 88° W., bringing its western end about 17 miles too far north, and reaching the (supposed) parallel of 35° at a distance of about 130 miles east of the Catawba River. The loss of territory resulting from these singular deviations is probably between 500 and 1,000 square miles.

The following extract from the constitution of 1796, of Tennessee,

defines the eastern boundary of that State, which is the western boundary of North Carolina, as it was intended to be run and marked:

Beginning on the extreme height of the Stone Mountain at the place where the line of Virginia intersects it in latitude thirty-six degrees and thirty minutes north; running thence along the extreme height of the said mountain to the place where Watauga River breaks through it; thence a direct course to the top of the Yellow Mountain, where Bright's road crosses the same; thence along the ridge of said mountain between the waters of Doe River and the waters of Rock Creek, to the place where the road crosses the Iron Mountain; from thence along the extreme height of said mountain to where Nolichucky River runs through the same; thence to the top of the Bald Mountain; thence along the extreme height of said mountain to the Painted Rock on French Broad River; thence along the highest ridge of said mountain to the place where it is called the Great Iron or Smoky Mountain; thence along the extreme height of said mountain to the place where it is called Unicoi or Unaka Mountain between the Indian towns of Cowee and Old Chota; thence along the main ridge of the said mountain to the southern boundary of this State as described in the act of cession of North Carolina to the United States of America.

In 1879 the legislature passed an act to appoint commissioners to make a survey from the northeast corner of Georgia westward. This point of commencement is common to North Carolina, South Carolina, and Georgia.

In 1881 the legislature passed another act, providing for the appointment of a commissioner, who should act with commissioners from Virginia, South Carolina, Georgia, or Tennessee, to re-run and re-mark the boundaries between North Carolina and the other States.

## SOUTH CAROLINA.

The territory included in the present State of South Carolina was included in the charter of Carolina, which also embraced what is now the State of Georgia. (*Vide* North Carolina, p. 93.)

In 1729 the province of Carolina was divided, forming the two provinces of North Carolina and South Carolina. In 1732 the extent of South Carolina was reduced by the charter of Georgia. (*Vide* Georgia, p. 97.)

(For a history of the settlement of the boundary between North Carolina and South Carolina, *vide* North Carolina, p. 93.)

By the charter of Georgia the line between South Carolina and Georgia was to be the Savannah River, to the head thereof. In 1762 difficulties having arisen, concerning the interpretation of the charter, as regarded the head of the Savannah, and also the title to the lands south of the Altamaha River, Georgia made complaint to the King, who issued a proclamation in 1763 giving the lands between the Altamaha and Saint Mary's Rivers to Georgia. The question of the boundary on the Savannah, however, remained unsettled until 1787, when a conven-

tion between the two States was held at Beaufort, S. C., to determine the same, and the line was fixed as at present.

The following is an extract from the articles of agreement:

The most northern branch or stream of the river Savannah from the sea or mouth of such stream to the fork or confluence of the rivers now called Tugaloo and Keowa, and from thence the most northern branch or stream of the said river Tugaloo till it intersects the northern boundary line of South Carolina, if the said branch or stream of Tugaloo extends so far north, reserving all the islands in the said rivers Savannah and Tugaloo to Georgia; but if the head spring or source of any branch or stream of the said river Tugaloo does not extend to the north boundary line of South Carolina, then a west line to the Mississippi, to be drawn from the head spring or source of the said branch or stream of Tugaloo River which extends to the highest northern latitude, shall forever hereafter form the separation, limit, and boundary between the States of South Carolina and Georgia. (Laws of the United States, Vol. I, p. 466.)

In the same year South Carolina ceded to the United States a narrow strip of territory south of the North Carolina line, which she claimed, about 12 or 14 miles wide, and extending to the Mississippi River; this strip now forms the northern portion of Georgia, Alabama, and Mississippi. Georgia being thus increased in extent northwardly, the line between the two States is clearly expressed in the code of South Carolina, as follows, viz:

The Savannah River, from its entrance into the ocean to the confluence of the Tugaloo and Keowa Rivers; thence by the Tugaloo River to the confluence of the Tugaloo and Chatooga Rivers; thence by the Chatooga River to the North Carolina line in the thirty-fifth degree of north latitude, the line being low-water mark at the southern shore of the most northern stream of said rivers, where the middle of the rivers is broken by islands, and middle thread of the stream where the rivers flow in one stream or volume.

## GEORGIA.

Georgia was included in the proprietary charter granted to the lords proprietors of Carolina in 1663 and 1665, for which a provincial charter was substituted in 1719.

In 1732 the charter of Georgia as an independent colony was granted by King George II, of which the following is an extract:

All those lands, countrys, and territories situate, lying and being in that part of South Carolina, in America, which lies from the most northern part of a stream or river there, commonly called the Savannah, all along the sea-coast to the southward, unto the most southern stream of a certain other great water or river called the Altamaha, and westerly from the heads of the said rivers, respectively, in direct lines to the south seas.

This charter was surrendered in 1752 and a provincial government established. (C. & C., p. 369 *et seq.*)

In 1763 the territory between the Altamaha and Saint Mary's Rivers was added to Georgia by royal proclamation. (*Vide* South Carolina, p. 96.)

In the constitution adopted by Georgia in 1798 the boundaries are declared. The following is an extract therefrom:

The limits, boundaries, jurisdictions, and authority of the State of Georgia do, and did, and of right ought to extend from the sea or mouth of the river Savannah along the northern branch or stream thereof, to the fork or confluence of the rivers now called Tugalo and Keowee, and from thence along the most northern branch or stream of the said river Tugalo, till it intersect the northern boundary line of South Carolina, if the said branch or stream of Tugalo extends so far north, reserving all the islands in the said rivers Savannah and Tugalo to Georgia; but if the head, spring, or source of any branch or stream of the said river Tugalo does not extend to the north boundary line of South Carolina, then a west line to the Mississippi, to be drawn from the head, spring, or source of the said branch or stream of Tugalo River, which extends to the highest northern latitude; thence down the middle of the said river Mississippi, until it shall intersect the northernmost part of the thirty-first degree of north latitude, south by a line drawn due east from the termination of the line last mentioned, in the latitude of thirty-one degrees north of the equator, to the middle of the river Apalachicola or Chatahoochee; thence along the middle thereof, to its junction with Flint River; thence straight to the head of Saint Mary's River, and thence, along the middle of Saint Mary's River, to the Atlantic Ocean, and from thence to the mouth or inlet of Savannah River, the place of beginning, including and comprehending all the lands and waters within the said limits, boundaries, and jurisdictional rights; and also all the islands within twenty leagues of the sea-coast.

In 1802 Georgia entered into articles of agreement and cession with the United States, whereby Georgia ceded to the United States the lands west of her present boundaries, and the United States ceded to Georgia that part of the South Carolina cession of 1787 which lies east of the present western boundary of Georgia. The following extracts show the limits of the two cessions:

The State of Georgia cedes to the United States all the right, title, and claim which the said State has to the jurisdiction and soil of the lands situated within the boundaries of the United States, south of the State of Tennessee and west of a line beginning on the western bank of the Chatahouchee River where the same crosses the boundary line between the United States and Spain; running thence up the said river Chatahouchee, and along the western bank thereof to the great bend thereof, next above the place where a certain creek or river, called "Uchee" (being the first considerable stream on the western side, above the Cussetas and Coweta towns), empties into the said Chatahouchee River; thence in a direct line to Nickajack, on the Tennessee River; thence crossing the said last-mentioned river, and thence running up the said Tennessee River and along the western bank thereof to the southern boundary line of the State of Tennessee.

* * * * * * *

The United States * * * cede to the State of Georgia * * * the lands * * * situated south of the southern boundaries of the States of Tennessee, North Carolina, and South Carolina, and east of the boundary line herein above described as the eastern boundary of the territory ceded by Georgia to the United States.

For a history of the boundary between Georgia and South Carolina, *vide* South Carolina, p. 96.

The history of the boundary between North Carolina and Georgia has already been given (*vide* North Carolina, p. 95). It may be proper, however, to add that this line (the thirty-fifth degree of north latitude) was fixed by the cession above detailed, from the United States to Georgia

of that part of the South Carolina cession east of the present western boundary of Georgia.

A long controversy ensued between Georgia and North Carolina, with no results, however, until in 1810 Georgia empowered her governor to employ Mr. Andrew Ellicott to ascertain the true location of the thirty-fifth degree of latitude. Ellicott did so, and the point fixed by him was acquiesced in. (*Vide* Cobb's Georgia Digest, p. 150.)

The boundary between Georgia and Tennessee was established in 1818, and is as follows, viz: The thirty-fifth parallel of north latitude, beginning and ending as follows:

Beginning at a point in the true parallel of the thirty-fifth degree of north latitude, as found by James Cormack, mathematician on the part of the State of Georgia, and James S. Gaines, mathematician on the part of the State of Tennessee, on a rock about two feet high, four inches thick, and fifteen inches broad, engraved on the north side thus: "June 1st, 1818; var. 6¼ east," and on the south side thus: "Geo. 35 North; J. Cormack," which rock stands one mile and twenty-eight poles from the south bank of the Tennessee River, due south from near the center of the old Indian town of Nickajack, and near the top of the Nickajack Mountain, at the supposed corner of the State of Georgia and Alabama; thence running due east, leaving old D. Ross two miles and eighteen yards in the State of Tennessee, and leaving the house of John Ross about two hundred yards in the State of Georgia, and the house of David McNair one mile and one-fourth of a mile in the State of Tennessee, with blazed and mile-marked trees, lessening the variation of the compass by degrees, closing it at the termination of the line on the top of the Unicoi Mountain at five and one-half degrees. (*Vide* C. Stat. of Tenn., pp. 243-244.)

The boundary between Georgia and Florida was fixed by the treaty of 1783, between the United States and Great Britain, substantially as at present, viz: Commencing in the middle of the Apalachicola or Catahouche River, on the thirty-first degree of north latitude; thence along the middle thereof to its junction with the Flint River; thence straight to the head of Saint Mary's River, and thence down along the middle of Saint Mary's River to the Atlantic ocean (*vide* Treaty of 1783). This boundary was affirmed by the treaty of 1795 between the United States and Spain, and commissioners were appointed to run the entire line between the United States and the Spanish territory. (*Vide* Treaty of 1795.)

In 1819 Spain ceded the Floridas to the United States. In 1822 Florida was made a Territory and in 1825 was admitted into the Union as an independent State.

In 1826 Congress took action as indicated below:

UNITED STATES STATUTES AT LARGE, NINETEENTH CONGRESS, SESSION I, 1826.

AN ACT to authorize the President of the United States to run and mark a line dividing the Territory of Florida from the State of Georgia.

The line shall be run straight from the junction of said rivers Chatahoochie and Flint, to the point designated as the head of Saint Mary's River.

This boundary ne wa long unsettled, a controversy arising concerning the true point to be considered to be the head of the Saint Mary's

River, as Georgia contended that the point fixed upon by the Spanish and American commissioners under the treaty of 1795 was incorrect.

In 1859 commissioners were appointed by Georgia and Florida to rerun the line. Florida ratified their report in 1861, and Georgia in 1866.

The detailed report of the commissioners is not at hand, but the line is declared in the statutes of Georgia as follows, viz:

From a point on the western bank of the Chattahochee River in the 31st degree of north latitude; thence along the line or limit of high-water mark to its junction with the Flint River; thence along a certain line of survey made by Gustavus J. Orr, a surveyor on the part of Georgia, and W. Whitner, a surveyor on the part of Florida, beginning at a four-and-aft tree, about four chains below the present junction; thence along this line east, to a point designated thirty-seven links north of Ellicott's Mound on the St. Mary's River; thence along the middle of said river to the Atlantic Ocean. (*Vide* Code of Ga., 1873, p. 7.)

This line is also given in the code of Florida, and differs in one respect, viz, from the thirty-first degree of north latitude down the middle of said river to its confluence with the Flint River, etc. (*Vide* Code of Florida, 1872.)

The line between Georgia and Alabama was fixed by the act of cession of Georgia to the United States in 1802.

In 1822–'25, Georgia desiring to have the line run from the Chattahoochee to where it strikes the Tennessee line, appointed commissioners for that purpose, and requested the co-operation of Alabama and the United States, both, however, failing to take action. The Georgia commissioners ran the line from Nickajack, on the Tennessee line, to Miller's Bend, on the Chattahoochee. (For a history of the controversy concerning this line, *vide* laws of Georgia, 1822–'24–'25–'26.)

Alabama protested against the above line and made repeated efforts to reopen negotiations concerning it, to all which Georgia sturdily refused to accede, until finally, January 24, 1840, the legislature of Alabama passed the following joint resolution, viz:

*Resolved*, That the State of Alabama will, and do, hereby accept, as the true dividing line between this State and that of Georgia, the line which was run and marked out by the commissioners of Georgia in 1826, beginning at what is called Miller's Bend, on the Chattahoochee River; thence along said marked line to Nickajack.

The line is given in the code of Alabama in the following words, viz:

The boundary line between Alabama and Georgia commences on the west side of the Chattahoochee River at the point where it enters the State of Florida; from thence up the river, along the western bank thereof, to the point on Miller's Bend next above the place where the Uchee Creek empties into such river; thence in a direct line to Nickajack. (See code of Alabama, 1876, p. 189.)

In James's Hand-book of Georgia, 1876, p. 121, is the following description of the western boundary of Georgia, viz:

From Nickajack the line between Georgia and Alabama runs south 9° 30′ east to Miller's Bend, on the Chattahoochee River, about 146 miles; thence down the western bank of the river at high-water mark to its junction with Flint River, at a point now four chains below the actual junction, latitude 30° 42′ 42″, longitude 80° 53′ 15″.

## FLORIDA.

Florida was originally settled by the Spaniards, and was held as a Spanish province nearly two hundred years. In 1762 it was ceded by Spain to Great Britain, who divided it into the two provinces of East and West Florida, separated by the Appalachicola River, with a northern boundary substantially as at present. (*Vide* Fairbanks' History of Florida.)

In 1783 Great Britain retroceded Florida to Spain, and the northern boundary was fixed by the treaty of peace between the United States and Great Britain signed in the same year. Spain, however, claimed the territory as far north as the parallel of latitude of the mouth of the Yazoo River.

Previous to this, in 1763, France had ceded Louisiana to Spain, which Spain retroceded to France in 1800, and in 1803 France ceded the same to the United States, who claimed that the eastern boundary of the said province of Louisiana, so often ceded, was the Perdido River, while Spain claimed it to be the Iberville River and Lakes Maurepas and Pontchartrain. The controversy arising from the difference of interpretation of these various treaties and cessions was terminated by the treaty of Washington in 1819, whereby Spain ceded to the United States the provinces of East and West Florida.

On March 30, 1822, by an act of Congress, the territory ceded to the United States by Spain was made the "Territory of Florida," embracing the same extent as does the present State.

On March 3, 1845, Florida was admitted into the Union as an independent State.

(For a history of the northern boundary of Florida *vide* Georgia, p. 99.)

In 1831 Congress passed an act relating to the boundary between Florida and Alabama, of which the following is an extract:

AN ACT to ascertain and mark the line between the State of Alabama and the Territory of Florida, and the northern boundary of the State of Illinois, and for other purposes.

That the President of the United States be, and he is hereby, authorized to cause to be run and marked the boundary line between the State of Alabama and the Territory of Florida, by the surveyors-general of Alabama and Florida, on the thirty-first degree of north latitude.

* * * * * * *

(*Vide* U. S. Stat. at Large, Vol. IV, p. 479.)

In 1847 the agreement of commissioners previously appointed by Florida and Alabama was ratified, and the line is described as follows, viz:

Commencing on the Chattahoochee River near a place known as "Irwin's Mills" and running west to the Perdido, marked throughout by blazes on the trees, and also by mounds of earth thrown up on the line at distances of one mile, more or less, from each other, and commonly known as "Ellicott's Line," or the "Mound Line." (*Vide* Florida Code, 1873, p. 100.)

The line between the two States is given in general terms in the Florida Code as follows, viz:

Commencing at the mouth of the Perdido River, from thence up the middle of said river to where it intersects the south boundary line of the State of Alabama and the thirty-first degree of north latitude; then due east to the Chattahoochee River.

## ALABAMA.

In 1798 the United States formed the Territory of Mississippi, including—

All that tract of country bounded on the west by the Mississippi, on the north by a line to be drawn due east from the mouth of the Yasous to the Chattahouchee River, on the east by the Chattahouchee River, and on the south by the thirty-first degree of north latitude. (*Vide* U. S. Stat. at Large, Vol. I, p. 549.)

In this act was a clause reserving the right of Georgia and of individuals to the jurisdiction of the soil thereof.

South Carolina and Georgia having ceded to the United States their claim to territory west of their present limits, the General Government, in 1804, by an act of Congress, annexed the tract of country lying north of Mississippi Territory and south of the State of Tennessee, and bounded on the east by Georgia and west by Louisiana, to the Territory of Mississippi. (*Vide* U. S. Stat. at Large, Vol. II, p. 305.) Also in 1812 the United States added to Mississippi Territory all the lands lying east of Pearl River, west of the Perdido and south of the thirty-first degree of latitude. (*Vide* U. S. Stat. at Large, Vol. II, p. 734.)

By these additions the Territory of Mississippi was made to comprise what is now included in the two States of Alabama and Mississippi. On March 8, 1817, by an act of Congress the Territory of Alabama was formed from the eastern portion of the Territory of Mississippi, with the following boundaries, viz:

Beginning at the point where the line of the thirty-first degree of north latitude intersects the Perdido River; thence east to the western boundary line of the State of Georgia; thence along said line to the southern boundary line of the State of Tennessee; thence west along said boundary line to the Tennessee River; thence up the same to the mouth of Bear Creek; thence by a direct line to the northwest corner of Washington County; thence due south to the Gulf of Mexico; thence, eastwardly, including all the islands within 6 leagues of the shore, to the Perdido River; and thence up the same to the beginning. (*Vide* U. S. Stat. at Large, Vol. III, p. 371.)

On December 14, 1819, Alabama was admitted as an independent State, with the above boundaries. It was, however, made the duty of the surveyor of the public lands south of Tennessee and the surveyor of lands in Alabama Territory to run and cut out the line of demarcation between the two States of Alabama and Mississippi, and if it should appear to said surveyors that so much of the line designated as

running due south from the northwest corner of Washington County to the Gulf of Mexico should encroach on the counties of Wayne, Greene, and Jackson, in the State of Mississippi, then the same should be altered so as to run in a direct line from the northwest corner of Washington County to a point on the Gulf of Mexico 10 miles east of the mouth of the River Pascagoula. (*Vide* U. S. Stat. at Large, Vol. III, p. 490.)

(For the history of the boundaries between Alabama and Georgia *vide* Georgia, p. 98. For the history of the boundaries between Alabama and Florida, *vide* Florida, p. 101.)

The boundary between Alabama and Tennessee is the thirty-fifth parallel of north latitude (*vide* North Carolina, p. 94); from Nickajack (*vide* Georgia, p. 98) west across the Tennessee River, and on to the second intersection of said river by said parallel. (*Vide* Alabama Code, 1876, p. 189.)

The boundary between Alabama and Mississippi was to be run by surveyors, under the act of admission of Alabama. The report of said surveyors is not at hand, but the line as laid down in the Mississippi Code is as follows, viz:

Beginning at a point on the west bank of the Tennessee River, six four-pole chains south of, and above, the mouth of Yellow Creek; thence up the said river to the mouth of Bear Creek; thence by a direct line to what was formerly the northwest corner of Washington County, Alabama; thence in a direct line to a point ten miles east of the Pascagoula River, on the Gulf of Mexico. (*Vide* Mississippi Code, pp. 48, 49).

## MISSISSIPPI.

(For the early history of the extent of Mississippi Territory *vide* Alabama, p. 102.)

On December 10, 1817, the western part of the Mississippi Territory was made a State and admitted into the Union, with the following boundaries, viz:

Beginning on the river Mississippi at the point where the southern boundary of the State of Tennessee strikes the same; thence east along the said boundary line to the Tennessee River; thence up the same to the mouth of Bear Creek; thence by a direct line to the northwest corner of the county of Washington; thence due south to the Gulf of Mexico; thence westwardly, including all the islands within six leagues of the shore, to the most eastern junction of Pearl River with Lake Borgne; thence up said river to the thirty-first degree of north latitude; thence west along said degree of latitude to the Mississippi River; thence up the same to the beginning. (*Vide* U. S. Stat. at Large, Vol. III, p. 348.)

(For further information concerning eastern boundary, *vide* Alabama, p. 102.)

In 1819 the line between Mississippi and Tennessee was run by commissioners. Their report is not at hand. In 1833 the legislature of

Tennessee passed an act establishing "Thompson's line." The details of "Thompson's line" have not been found. In 1837 the line was again run by commissioners from the two States, and ratified by the legislatures. The commissioners' report was as follows, viz:

Commencing at a point on the west bank of the Tennessee River six four-pole chains south, or above the mouth of Yellow Creek, and about three-quarters of a mile north of the line known as "Thompson's line," and twenty-six chains and ten links north of Thompson's line at the basis meridian of the Chickasaw surveys, and terminating at a point on the east bank of the Mississippi River (opposite Cow Island) sixteen chains north of Thompson's line. (See Laws of Tennessee, 1837, p. 27.)

The boundaries were fixed by the act of Congress admitting the State of Mississippi, as follows, viz:

Commencing at the most eastern junction of Pearl River with Lake Borgne, thence up said Pearl River to the thirty-first degree of north latitude, thence west along said degree of latitude to the Mississippi River, thence up the same to the point where the southern boundary of Tennessee strikes the same. (See U. S. Laws, vol. 6, p. 175.)

Mississippi claims to the middle of the Mississippi River, where the river forms her western boundary. (See Rev. Stat., 1857.)

## LOUISIANA.

The original territory of Louisiana was acquired from France (see p. 19). In 1804, a portion of this, comprising the area of the present State of Louisiana, with the exception of the southeastern portion immediately adjoining the present State of Florida, was organized into a territory under the name of Orleans, while the balance of the Louisiana purchase retained the name of Louisiana Territory. On April 30, 1812, the Territory of Orleans was admitted as a State under the name of Louisiana, and at the same time the name of the Territory of Louisiana was changed to Missouri Territory. In the same year the limits of the State were enlarged in the southeast to its present boundaries.

The following act defines the Territory of Orleans:

All that portion of country ceded by France to the United States, under the name of Louisiana, which lies south of the Mississippi territory, and of an east and west line to commence on the Mississippi River at the thirty-third degree of north latitude, and to extend west to the western boundary of the said cession, shall constitute a Territory of the United States, under the name of the Territory of Orleans. (Eighth Congress, first session.)

The following clause from the act admitting Louisiana defines its original boundaries:

Beginning at the mouth of the river Sabine, thence by a line to be drawn along the middle of said river, including all islands, to the thirty-second degree of latitude; thence due north to the northernmost part of the thirty-third degree of north latitude; thence along the said parallel of latitude to the river Mississippi; thence down

the said river to the river Iberville; and from thence along the middle of the said river and lakes Maurepas and Pontchartrain to the Gulf of Mexico; thence, bounded by the said Gulf, to the place of beginning, including all islands within three leagues of the coast. (Twelfth Congress, first session.)

The following is a description of the addition to the State of Louisiana, in terms of the act:

Beginning at the junction of the Iberville with the river Mississippi, thence along the middle of the Iberville, the river Amite, and of the lakes Maurepas and Pontchartrain, to the eastern mouth of the Pearl River; thence up the eastern branch of Pearl River to the thirty-first degree of north latitude; thence along the said degree of latitude to the river Mississippi; thence down the said river to the place of beginning, shall become and form a part of the State of Louisiana. (Twelfth Congress, first session.)

## TEXAS.

Texas declared its independence of Mexico in 1835. On December 29, 1845, it was admitted to the Union. As originally constituted, it embraced besides its present area the region east of the Rio Grande, now in New Mexico, extending north to the Arkansas River, its eastern limits coinciding with the western limit of the United States, as laid down in the treaty with Spain of 1819.

In 1848, the eastern boundary of the State was extended slightly, as noted in the following act:

*Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,* That this Congress consents that the legislature of the State of Texas may extend her eastern boundary so as to include within her limits one-half of Sabine Pass, one-half of Sabine Lake, also one-half of Sabine River, from its mouth as far north as the thirty-second degree of north latitude.

In 1850, the State sold to the General Government, for the sum of $10,000,000, that part lying north of the parallel of 36° 30′, and that portion lying west of longitude 103°, as far south as the parallel of 32°, as set forth in the following clause from the act of Congress relating to this transfer:

First. The State of Texas will agree that her boundary on the north shall commence at the point at which the meridian of one hundred degrees west from Greenwich is intersected by the parallel of thirty-six degrees thirty minutes north latitude, and shall run from said point due west to the meridian of one hundred and three degrees west from Greenwich; thence her boundary shall run due south to the thirty-second degree of north latitude; thence on the said parallel of thirty-two degrees of north latitude to the Rio Bravo del Norte, and thence with the channel of said river to the Gulf of Mexico. (Thirty-first Congress, first session.)

The following act defines the northern boundary of Texas:

AN ACT to authorize the President of the United States, in conjunction with the State of Texas, to run and mark the boundary lines between the Territories of the United States and the State of Texas.

Beginning at the point where the one hundredth degree of longitude west from Greenwich crosses Red River, and running thence north to the point where said one

hundredth degree of longitude intersects the parallel of thirty-six degrees thirty minutes north latitude, and thence west with the said parallel of thirty-six degrees and thirty minutes north latitude to the point where it intersects the one hundred and third degree of longitude west from Greenwich; and thence south with the said one hundred and third degree of longitude to the thirty-second parallel of north latitude; and thence west with said thirty-second degree of north latitude to the Rio Grande. (Thirty-fifth Cong., first session.)

The boundary line of Texas is as follows:

Beginning in the Gulf of Mexico, at the outlet of Sabine Lake, the line passes northward through the middle of Sabine Lake and up the middle of Sabine River to the point where said river intersects the parallel of thirty-two degrees; thence north along the meridian of that point of intersection to the point where said meridian intersects Red River; thence up Red River to the one hundredth meridian west of Greenwich; thence north on said meridian to the parallel of thirty-six degrees thirty minutes; west on said parallel to the meridian of one hundred and three degrees west of Greenwich; thence south on said meridian to the parallel of latitude of 32°; thence west on that parallel to its point of intersection with the Rio Grande; thence down the mid-channel of the Rio Grande to its mouth.

## ARKANSAS

The Territory of Arkansas, or Arkansaw, as it was originally spelled, was formed on March 2, 1819, from a part of Missouri Territory. The following clause from the act establishing it defines its limits in part:

All that part of the Territory of Missouri which lies south of a line beginning on the Mississippi River at thirty-six degrees north latitude, running thence west to the River St. François, thence up the same to 36° 30′ north latitude, and thence west to the western territorial boundary line, shall, for the purposes of a Territorial government, constitute a separate Territory and be called the Arkansaw Territory.

In 1824 an act was passed by Congress fixing the western boundary of the Territory. This was as follows:

AN ACT to fix the western boundary line of the Territory of Arkansas, and for other purposes.

The western boundary line of the Territory of Arkansas shall begin at a point forty miles west of the southwest corner of the State of Missouri and run south to the right bank of the Red River, and thence down the river and with the Mexican boundary to the line of the State of Louisiana.

Four years later, in 1828, the following act was passed defining its southern boundary:

AN ACT to authorize the President of the United States to run and mark a line dividing the Territory of Arkansas from the State of Louisiana.

Commencing on the right bank of the Mississippi River at latitude thirty-three degrees north and running due west on that parallel of latitude to where a line running due north from latitude thirty-two degrees north on the Sabine River will intersect the same.

The same year the following treaty changed materially the western line of the Territory, placing it in its present position.

TREATY WITH THE CHEROKEE INDIANS MAY 28, 1828.

ARTICLE 1.—The western boundary of Arkansas shall be, and the same is, hereby defined, viz: A line shall be run, commencing on Red River at the point where the Eastern Choctaw line strikes said river, and run due north with said line to the River Arkansas; thence in a line to the southwest corner of Missouri.

The Eastern Choctaw line, referred to above, starts on the Arkansas River, "one hundred paces west of Fort Smith, and thence due south to the Red River." (Treaty with Choctaw Nation, January 20, 1825.)

Arkansas was admitted as a State June 15, 1836.

The following extracts from the enabling act, and from various constitutions, give statements of the boundaries, differing slightly from one another, but, for the most part, only in wording:

CONSTITUTION OF ARKANSAS, 1836.

Beginning in the middle of the main channel of the Mississippi River on the parallel of 36 degrees north latitude; running from thence west with the parallel of latitude to the Saint Francis River; thence up the middle of the main channel of said river to the parallel of thirty-six degrees thirty minutes north; from thence west to the southwest corner of the State of Missouri; and from thence to be bounded on the west to the north bank of Red River, as by acts of Congress and treaties heretofore defining the western limits of the Territory of Arkansas, and to be bounded on the south side of Red River by the Mexican boundary line to the northwest corner of the State of Louisiana; thence east by the Louisiana state line to the middle of the main channel of the Mississippi River; thence up the middle of the main channel of said river to the thirty-sixth degree of north latitude, the point of beginning.

Again, in the enabling act for Arkansas, 1836 (Twenty-fourth Congress, first session), the boundaries are found to be defined as follows:

Beginning in the middle of the main channel of the Mississippi River, on the parallel of thirty-six degrees north latitude, running from thence west, with the said parallel of latitude, to the St. Francis River; thence up the middle of the main channel of said river to the parallel of thirty-six degrees thirty minutes north; from thence west to the southwest corner of the State of Missouri; and from thence to be bounded on the west, to the north bank of Red River, by the line described in the first article of the treaty between the United States and the Cherokee Nation of Indians, west of the Mississippi, made and concluded at the city of Washington, on the twenty-sixth day of May, in the year of our Lord one thousand eight hundred and twenty-eight; and to be bounded on the south side of Red River by the Mexican boundary line to the northwest corner of the State of Louisiana; thence east with the Louisiana state line to the middle of the main channel of the Mississippi River; thence up the middle of the main channel of the said river to the thirty-sixth degree of north latitude, the point of beginning.

In the constitution of 1864 the boundaries are defined as follows:

Beginning in the middle of the Mississippi River, on the parallel of thirty-six degrees north latitude, to the St. Francis River; thence up the middle of the main channel of said river to the parallel of thirty-six degrees thirty minutes north, thence west to the southwest corner of the State of Missouri; and from thence to be bounded on the west to the north bank of Red River, as by acts of Congress of the United States, and the treaties heretofore defining the western limits of the Territory of Arkansas; and to be bounded on the south side of Red River by the boundary line of the State of Texas, to the northwest corner of the State of Louisiana; thence east with the Louisiana state line to the middle of the main channel of the Mississippi River;

thence up the middle of the main channel of said river to the thirty-sixth degree of north latitude, the point of beginning.

The constitution of 1868 differs but slightly from the last. It is as follows:

Beginning at the middle of the main channel of the Mississippi River, on the parallel of 36° north latitude, running from thence west, with the said parallel of latitude, to the Saint Francis River; thence up the middle of the main channel of said river to the parallel of 36° 30′ north; from thence west with the boundary line of the State of Missouri to the southwest corner of that State; and thence to be bounded on the west to the north bank of Red River, as by acts of Congress and treaties heretofore defining the western limits of the Territory of Arkansas; and to be bounded on the south side of Red River by the boundary line of the State of Texas to the northwest corner of the State of Louisiana; thence east with the Louisiana State line to the middle of the main channel of the Mississippi River; thence up the middle of the main channel of said river, including an island in said river known as "Belle Point Island," to the 36° of north latitude, the place of beginning.

In the constitution of 1874 there are again slight differences, mainly in wording.

Beginning at the middle of the main channel of the Mississippi River, on the parallel of thirty-six degrees of north latitude; running thence west with said parallel of latitude to the middle of the main channel of the Saint Francis River; thence up the main channel of said last-named river to the parallel of thirty-six degrees thirty minutes of north latitude; thence west with the southern boundary line of the State of Missouri to the southwest corner of said last-named State; thence to be bounded on the west to the north bank of Red River, as by act of Congress and treaties existing January 1, 1837, defining the western limits of the Territory of Arkansas and to be bounded across and south of Red River by the boundary line of the State of Texas as far as to the northwest corner of the State of Louisiana; thence easterly with the northern boundary line of said last-named State, to the middle of the main channel of the Mississippi River; thence up the middle of the main channel of said last-named river, including an island in said river known as "Belle Point Island," and all other land originally surveyed and included as a part of the Territory or State of Arkansas to the thirty-sixth degree of north latitude, the place of beginning.

## TENNESSEE.

Tennessee was originally a part of North Carolina. (For further information *vide* North Carolina, p. 92.)

In 1790 it was ceded to the United States. Its boundaries described in the act of cession are, substantially, those of the present day.

On June 1, 1796, by an act of Congress it was admitted into the Union.

The act of admission declares its boundaries, as "All the territory ceded by North Carolina."

(For the history of the eastern boundary *vide* North Carolina, p. 94; for the southern boundary *vide* Georgia, p. 99, Alabama, p. 103, and Mississippi, p. 103.)

The Mississippi River forms its western boundary under the treaty of peace of 1783.

The line which divided Virginia and North Carolina was the southern boundary of Kentucky. Virginia and North Carolina, prior to the creation of the States of Kentucky and Tennessee, appointed commissioners, Messrs. Walker and Henderson, to run and mark the line on the parallel of latitude 36° 30′. From a point on the top of the Cumberland Mountains, now the southeastern corner of Kentucky, Walker ran and marked the line to a point on the Tennessee River. This line, called Walker's line, was regarded for many years as the dividing line between Kentucky and Tennessee. It was ascertained, however, that Walker's line was north of latitude 36° 30′.

The Indian title to the land west of the Tennessee River being extinguished by the treaty of 1819, the legislature appointed Robert Alexander and Luke Munsell to ascertain the true point of latitude 36° 30′ on the Mississippi River, and to run and mark a line east on that parallel, which was done as far east as the Tennessee River. (For above, see Gen. Stat. Ky., 1873, p. 167.)

In 1820 commissioners were appointed by Kentucky and Tennessee, respectively, to settle the boundary. Their report was ratified, and is as follows, viz:

ART. I. The line of boundary and separation between the States of Kentucky and Tennessee shall be as follows, viz:

The line run by the Virginia commissioners in the year 1779–'80, commonly called Walker's line, as the same is reputed, understood, and acted upon by the said States, their respective officers and citizens, from the southeastern corner of Kentucky to the Tennessee River; thence with and up said river to the point where the line of Alexander and Munsell, run by them in the last year under the authority of an act of the legislature of Kentucky entitled "An act to run the boundary line between this State and the State of Tennessee, west of the Tennessee River, approved Feb. 8, 1819," would cross said river, and thence with the said line of Alexander and Munsell, to the termination thereof on the Mississippi River below New Madrid.

Then follow nine other articles.

Article III provides for running and marking the line at any subsequent time. (See General Stat. Kentucky, page 170.)

In 1858–'59 commissioners were appointed by Kentucky and Tennessee to run this line.

The detailed report can be found in Statutes of Tennessee, 1871, Vol. I, pages 223–243, giving courses, bearings, mile-stones erected, and a map of the boundary.

(For a history of the boundary between Virginia and Tennessee, *vide* Virginia, p. 91.)

## KENTUCKY.

Kentucky was included in the original limits of Virginia, and was a part of the county of Augusta. Augusta County was formed in 1738. In 1769 Botetourt County was created from a portion of Augusta County; in 1772, Fincastle from Botetourt; in 1776, Kentucky from Fincastle.

The boundaries of all these counties may be found in Hening's Law of Virginia, Vols. I to IX.

In 1789 Virginia passed an act giving her consent that the county of Kentucky, within her jurisdiction, should be formed into a new State. Accordingly, June 1, 1792, Kentucky was admitted into the Union, with substantially her present boundaries.

By the cession of 1784, by Virginia to the United States, of the territory northwest of the Ohio River, this river became the northwest boundary of the State of Kentucky.

The western boundary, the Mississippi, was fixed by the treaty of peace in 1783.

(For a history of the boundary between Kentucky and Virginia and West Virginia, *vide* Virginia, p. 90, for the boundary between Kentucky and Tennessee, *vide* Tennessee, p. 109.)

## OHIO.

Ohio was the first State formed from the original territory northwest of the river Ohio. It was admitted as a State on November 29, 1802, with limits given in the enabling act as follows:

Bounded on the east by the Pennsylvania line, on the south by the Ohio River, to the mouth of the Great Miami River, on the west by the line drawn due north from the mouth of the Great Miami aforesaid, and on the north by an east and west line drawn through the southerly extreme of Lake Michigan, running east after intersecting the due-north line aforesaid, from the mouth of the Great Miami until it shall intersect Lake Erie or the territorial line; and thence with the same through Lake Erie to the Pennsylvania line aforesaid: *Provided*, That Congress shall be at liberty at any time hereafter either to attach all the territory lying east of the line to be drawn due north from the mouth of the Miami aforesaid to the territorial line, and north of an east and west line drawn through the southerly extreme of Lake Michigan, running east as aforesaid to Lake Erie, to the aforesaid State, or dispose of it otherwise, in conformity to the fifth article of compact between the original States and the people and States to be formed in the territory northwest of the river Ohio. (Seventh Congress, first session.)

In the constitution of Ohio of 1802, Article VII, the boundaries are defined as follows:

Bounded on the east by the Pennsylvania line; on the south by the Ohio River, to the mouth of the Great Miami River; on the west by the line drawn due north from the mouth of the great Miami aforesaid; and on the north by an east and west line drawn through the southerly extreme of Lake Michigan, running east after intersecting the due north line aforesaid from the mouth of the Great Miami, until it shall intersect Lake Erie or the territorial line; and thence with the same through Lake Erie to the Pennsylvania line aforesaid; provided always, and it is hereby fully understood and declared by this convention, that if the southerly bend or extreme of Lake Michigan should extend so far south that a line drawn due east from it should

not intersect Lake Erie, or if it should intersect the said Lake Erie east of the mouth of the Miami River of the Lake, then, and in that case, with the assent of the Congress of the United States, the northern boundary of this State shall be established by, and extending to, a direct line running from the southern extremity of Lake Michigan to the most northerly cape of the Miami Bay, after intersecting the due-north line from the mouth of the Great Miami River as aforesaid; thence northeast to the territorial line, and by the said territorial line to the Pennsylvania line.

In accordance with the provisions in the enabling act, and in the first constitution of the State, the northern boundary of the State was changed so that, instead of running on a parallel drawn from the southern extremity of Lake Michigan, it followed the arc of a great circle drawn from the southern extremity of Lake Michigan to the most northern cape of Maumee ("Miami") Bay.

Following are the text of the act providing for the examination of the northern boundary and that of the act making the change in the boundary.

AN ACT to provide for the taking of certain observations preparatory to the adjustment of the northern boundary line of the State of Ohio.

That the President of the United States cause to be ascertained, by accurate observation, the latitude and longitude of the southerly extreme of Lake Michigan; and that he cause to be ascertained, by like observation, the point on the Miami of the Lake which is due east therefrom, and also the latitude and longitude of the most northerly cape of the Miami Bay; also, that he cause to be ascertained, with all practicable accuracy, the latitude and longitude of the most southerly point in the northern boundary line of the United States in Lake Erie, and also the points at which a direct line drawn from the southerly extreme of Lake Michigan to the most southerly point in said northern boundary line of the United States will intersect the Miami River and Bay; and also that he cause to be ascertained, by like observation, the point in the Mississippi which is due west from the southerly extreme of Lake Michigan; and that the said observations be made and the result thereof returned to the proper Department within the current year. (Twenty-second Congress, first session, 1832.)

AN ACT to establish the northern boundary line of the State of Ohio, and to provide for the admission of the State of Michigan into the Union.

The northern boundary line of the State of Ohio shall be established at and shall be a direct line drawn from the southern extremity of Lake Michigan to the most northerly cape of the Maumee (Miami) Bay after that line, so drawn, shall intersect the eastern boundary line of the State of Indiana; and from the said north cape of the said bay northeast to the boundary line between the United States and the province of Upper Canada, in Lake Erie, and thence, with the said last-mentioned line, to its intersection with the western line of the State of Pennsylvania. (Twenty-fourth Congress, first session, 1836.)

## INDIANA.

By the act passed in the year 1800, to take effect on and after the 4th day of July of that year, the Territory Northwest of the River Ohio was divided into two parts, the eastern part to retain the old name, the western part to become the Territory of Indiana.

Under this act the Territory of Indiana was organized. The description of the boundary line between these two Territories is given in the following act establishing them:

That from and after the fourth day of July next all that part of the territory of the United States northwest of the Ohio River, which lies to the westward of a line beginning at the Ohio, opposite to the mouth of Kentucky River, and running thence to Fort Recovery, and thence north until it shall intersect the territorial line between the United States and Canada, shall, for the purpose of temporary government, constitute a separate Territory, and be called Indiana Territory.

SEC. 5. That whenever that part of the territory of the United States which lies to the eastward of a line beginning at the mouth of the Great Miami River, and running thence due north to the territorial line between the United States and Canada, shall be erected into an independent State, and admitted into the Union on an equal footing with the original States, thenceforth said line shall become and remain permanently the boundary line between such State and the Indiana Territory, anything in this act contained to the contrary notwithstanding. (Sixth Congress, first session.)

Ohio was admitted in 1802. Its western boundary, a meridian through the mouth of the Miami River, left a narrow strip of country between Ohio and the Territory of Indiana, which was by a clause in the enabling act of Ohio added to Indiana Territory. The following is the clause in question:

SEC. 3. All that part of the territory of the United States northwest of the river Ohio heretofore included in the eastern division of said Territory, and not included within the boundary herein prescribed for the said State, is hereby attached to and made a part of the Indiana Territory.

On the 30th of June, 1805, the northern portion of Indiana Territory was cut off and organized as Michigan Territory. (For the divisional line between these, see Michigan, p. 113.)

On March 1, 1809, Indiana Territory was divided, and the western portion of it organized as Illinois Territory. (For a description of the divisional line between these two Territories, see Illinois, p. 113.) On December 11, 1816, Indiana was admitted as a State with the limits as given in the following extract from the enabling act, which have not since been changed:

AN ACT to enable the people of the Indiana Territory to form a constitution and State government, and for the admission of such State into the Union on an equal footing with the original States.

The said State shall consist of all the territory included within the following boundaries, to wit: Bounded on the east by the meridian line which forms the western boundary of the State of Ohio; on the south by the river Ohio from the mouth of the Great Miami River to the mouth of the river Wabash; on the west by a line drawn along the middle of the Wabash from its mouth to a point where a due north line drawn from the town of Vincennes would last touch the northwestern shore of the said river; and from thence by a due north line, until the same shall intersect an east and west line drawn through a point 10 miles north of the southern extreme of Lake Michigan; on the north by the said east and west line until the same shall intersect the first-mentioned meridian line which forms the western boundary of the State of Ohio. (Fourteenth Congress, first session.)

## ILLINOIS.

Illinois Territory, originally part of the Northwest Territory, and subsequently a part of Indiana Territory, was organized on March 1, 1809. The following clause from the act separating it from Indiana Territory defines its boundary:

AN ACT for dividing the Indiana Territory into two separate governments.

From and after the first day of March next, all that part of the Indiana Territory which lies west of the Wabash River and a direct line drawn from the said Wabash River and Post Vincennes due north to the territory line between the United States and Canada shall, for the purpose of temporary government, constitute a separate Territory and be called Illinois. (Tenth Congress, second session.)

On December 3, 1818, it was admitted as a State, with its present boundaries. The enabling act defines these boundaries as follows:

AN ACT to enable the people of the Illinois Territory to form a constitution and State government, and for the admission of such State into the Union on an equal footing with the original States.

The said State shall consist of all the territory included within the following boundaries, to wit: Beginning at the mouth of the Wabash River; thence up the same and with the line of Indiana to the northwest corner of said State; thence east with the line of the same State to the middle of Lake Michigan; thence north along the middle of said lake to north latitude forty-two degrees thirty minutes; thence west to the middle of the Mississippi River; and thence down along the middle of that river to its confluence with the Ohio River; and thence up the latter river along its northwestern shore to the beginning. (Fifteenth Congress, second session.)

## MICHIGAN.

Michigan was organized as a Territory June 30, 1805, from the northern part of Indiana Territory.

The following clause from the act dividing Indiana Territory defines its limits:

From and after the thirtieth day of June next all that part of the Indiana Territory which lies north of a line drawn east from the southerly bend or extreme of Lake Michigan, until it shall intersect Lake Erie, and east of a line drawn from the said southerly bend through the middle of said lake to its northern extremity, and thence due north to the northern boundary of the United States, shall, for the purpose of temporary government, constitute a separate Territory, and be called Michigan. (Eighth Congress, second session.)

The enabling act for Illinois, passed in 1818, contained a provision transferring to the Territory of Michigan the portion of the Territory of Illinois not included in the State of that name. The following is the text of the clause referred to:

All that part of the territory of the United States lying north of the State of Indiana, and which was included in the former Indiana Territory, together with that part of the Illinois Territory which is situated north of and not included within the bound-

aries prescribed by this act, to the State thereby authorized to be formed, shall be, and hereby is, attached to and made a part of the Michigan Territory, from and after the formation of the said State.

In 1834 an act was passed extending the limits of the Territory of Michigan to the Missouri River.

The clause of this act relating to area is as follows:

AN ACT to attach the territory of the United States west of the Mississippi River and north of the State of Missouri to the Territory of Michigan.

All that part of the territory of the United States bounded on the east by the Mississippi River, on the south by the State of Missouri and a line drawn due west from the northwest corner of said State to the Missouri River; on the southwest and west by the Missouri River and the White Earth River, falling into the same; and on the north by the northern boundary of the United States, shall be, and hereby is, for the purpose of temporary government, attached to and made a part of the Territory of Michigan.

In 1836 Wisconsin Territory was formed from that part of Michigan Territory lying west of the present limits of the State of that name. (*Vide* Wisconsin, p. 115.)

Reduced to its present limits, as described in the following clause from its enabling act, Michigan was admitted to the Union January 26, 1837:

AN ACT to provide for the admission of the State of Michigan into the Union.

Beginning at the point where the above-described northern boundary of the State of Ohio intersects the eastern boundary of the State of Indiana, and running thence with the said boundary line of Ohio, as described in the first section of this act, until it intersects the boundary line between the United States and Canada in Lake Erie: thence with the said boundary line between the United States and Canada through the Detroit River, Lake Huron, and Lake Superior, to a point where the said line last touches Lake Superior; thence in a direct line through Lake Superior to the mouth of the Montreal River; thence through the middle of the main channel of the said river Montreal to the middle of the Lake of the Desert; thence in a direct line to the nearest headwater of the Menomonee River; thence through the middle of that fork of the said river first touched by the said line to the main channel of the said Menomonee River; thence down the center of the main channel of the same to the center of the most usual ship channel of the Green Bay of Lake Michigan; thence through the center of the most usual ship channel of the said bay to the middle of Lake Michigan; thence through the middle of Lake Michigan to the northern boundary of the State of Indiana, as that line was established by the act of Congress of the nineteenth of April, eighteen hundred and sixteen; thence due east with the north boundary line of the said State of Indiana to the northeast corner thereof; and thence south, with the east boundary line of Indiana, to the place of beginning. (Twenty-fourth Congress, first session.)

The above boundaries remain unchanged.

## WISCONSIN.

Wisconsin was organized as a Territory July 3, 1836. As originally constituted its area comprised all that part of the former Territory of

Michigan which lay outside of the present limits of the State of Michigan. The limits are defined in the act for its organization as follows:

Bounded on the east by a line drawn from the northeast corner of the State of Illinois, through the middle of Lake Michigan, to a point in the middle of said lake and opposite the main channel of Green Bay, and through said channel and Green Bay to the mouth of the Menomonee; thence through the middle of the main channel of said river to that head of said river nearest to the Lake of the Desert; thence in a direct line to the middle of said lake; thence through the middle of the main channel of the Montreal River to its mouth; thence with a direct line across Lake Superior to where the territorial line of the United States last touches said lake northwest; thence on the north with the said territorial line to the White Earth River, on the west by a line from the said boundary line following down the middle of the main channel of White Earth River to the Missouri River, and down the middle of the main channel of the Missouri River to a point due west from the northwest corner of the State of Missouri, and on the south, from said point, due east to the northwest corner of the State of Missouri; and thence with the boundaries of the States of Missouri and Illinois, as already fixed by acts of Congress. (Twenty-fourth Congress, first session.)

In 1838 all that part of the territory lying west of the Mississippi and a line drawn due north from its source to the international boundary—that is, all that part which was originally comprised in the Louisiana purchase—was organized as the Territory of Iowa. (See Iowa, p. 117.)

On August 9, 1846, an enabling act for Wisconsin was passed giving the boundaries as follows:

Beginning at the northeast corner of the State of Illinois, that is to say, at a point in the center of Lake Michigan where the line of forty-two degrees and thirty minutes of north latitude crosses the same; thence running with the boundary line of the State of Michigan, through Lake Michigan, Green Bay, to the mouth of the Menomonee River; thence up the channel of said river to the Brulè River; thence up said last-mentioned river to Lake Brulè; thence along the southern shore of Lake Brulè in a direct line to the center of the channel between Middle and South Islands in the Lake of the Desert; thence in a direct line to the headwaters of Montreal River, as marked upon the survey made by Captain Cramm; thence down the main channel of the Montreal River to the middle of Lake Superior; thence through the center of Lake Superior to the mouth of the Saint Louis River, thence up the main channel of said river to the first rapids in the same, above the Indian village, according to Nicollet's map; thence due south to the main branch of the river Saint Croix; thence down the middle of the main channel of said river to the Mississippi; thence down the center of the main channel of that river to the northwest corner of the State of Illinois; thence due east with the northern boundary of the State of Illinois to the place of beginning. (Twenty-ninth Congress, first session.)

On March 3, 1847, a supplementary act for the admission of Wisconsin was passed by Congress, in which the western boundary of the proposed State was changed as follows:

That the assent of Congress is hereby given to the change of boundary proposed in the first article of said constitution, to wit: Leaving the boundary line prescribed in the act of Congress entitled "An act to enable the people of Wisconsin Territory to form a constitution and State government, and for the admission of such State into the Union," at the first rapids in the river St. Louis; thence in a direct line southwardly to a point fifteen miles east of the most easterly point of Lake St. Croix;

thence due south to the main channel of the Mississippi River or Lake Pepin; thence down the said main channel, as prescribed in said act. (Twenty-ninth Congress, second session.)

On May 29, 1848, Wisconsin was admitted into the Union.

## MISSOURI.

The name of the Territory of Louisiana was changed in 1812 to Missouri, by act of Congress. At that time the Territory comprised all of the original Louisiana purchase, excepting the State of Louisiana, which had been formed from it. The Territory of Arkansas, with limits very similar to those of the present State, was formed from it in 1819. On August 10, 1821, the *State* of Missouri was formed and admitted, with limits, excepting as to the northwest corner, the same as at present.

Boundaries are defined as follows:

Beginning in the middle of the Mississippi River, on the parallel of thirty-six degrees of north latitude; thence west along that parallel of latitude to the Saint Francois River; thence up, and following the course of that river, in the middle of the main channel thereof, to the parallel of latitude of thirty-six degrees and thirty minutes; thence west, along the same, to a point where the said parallel is intersected by a meridian-line passing through the middle of the mouth of the Kanaas River, where the same empties into the Missouri River; thence from the point aforesaid north, along the said meridian line to the intersection of the parallel of latitude which passes through the rapids of the river Des Moines, making the said line to correspond with the Indian boundary line; thence east from the point of intersection last aforesaid, along the said parallel of latitude, to the middle of the channel of the main fork of the said river Des Moines; thence down and along the middle of the main channel of the said River Des Moines to the mouth of the same where it empties into the Mississippi River; thence due east to the middle of the main channel of the Mississippi River; thence down and following the course of the Mississippi River in the middle of the main channel thereof, to the place of beginning. (Sixteenth Congress, first session.)

In 1836 the boundaries were extended on the northwest to the Missouri River, as described in the following act of the legislature amendatory to the constitution of 1820:

That the boundary of the State be so altered and extended as to include all that tract of land lying on the north side of the Missouri River and west of the present boundary of this State, so that the same shall be bounded on the south by the middle of the main channel of the Missouri River, and on the north by the present northern boundary line of the State, as established by the constitution, when the same is continued in a right line to the west, or to include so much of said tract of land as Congress may assent.

This was ratified by Congress in the following act:

AN ACT to extend the western boundary of the State of Missouri to the Missouri River.

That when the Indian title to all the lands lying between the State of Missouri and the Missouri River shall be extinguished, the jurisdiction over said lands shall be hereby ceded to the State of Missouri, and the western boundary of said State shall be then extended to the Missouri River. (Twenty-fourth Congress, first session.)

The territory remaining after the formation of the State bore the name of Missouri for many years thereafter. Meanwhile, however, it was reduced by the formation of several Territories which were carved from its area. In 1834, the part north of the State of Missouri and east of the Missouri and White Earth Rivers was annexed to the territory of Michigan. (For further history of this portion, *vide* Michigan, p. 114; Iowa, below; Minnesota, p. 118; and Dakota, p. 121.) In 1854 Kansas and Nebraska Territories were formed, absorbing the remainder. (*Vide* Kansas, p. 119, and Nebraska, p. 120.)

The following are the boundaries of Missouri as at present established: The east boundary is the mid-channel of the Mississippi River from the mouth of the Des Moines to its point of intersection with the thirty-sixth parallel of latitude; the south boundary begins at the latter point and runs west on the parallel of 36 degrees of latitude to the Saint Francis River, thence up the mid-channel of that river to the parallel of latitude 36° 30′, thence west on that parallel to its intersection by a meridian passing through the middle of the mouth of the Kansas River; the west boundary is the last mentioned meridian as far north as the mouth of the Kansas River, thence it follows northwestward the mid-channel of the Missouri River to the parallel of latitude 40° 30′; the north boundary is the last-mentioned parallel as far east as its point of intersection with the Des Moines River, whence it follows the mid-channel of the Des Moines River southward to its mouth.

## IOWA.

Iowa was organized as a Territory on July 3, 1838, being formed from a portion of Wisconsin Territory. The limits were defined as follows in the act creating it:

All that part of the present Territory of Wisconsin which lies west of the Mississippi River and west of the line drawn due north from the headwaters or sources of the Mississippi to the Territorial line. (Twenty-fifth Congress, second session. See Wisconsin, p. 115.)

The following clause from an act passed in 1839 is supplementary to the above act:

AN ACT to define and establish the eastern boundary line of the Territory of Iowa.

That the middle or centre of the main channel of the river Mississippi shall be deemed, and is hereby declared, to be the eastern boundary line of the Territory of Iowa, so far or to such extent as the said Territory is bounded eastwardly by or upon said river. (Twenty-fifth Congress, third session.)

Iowa was admitted to the Union on March 3, 1845. As originally constituted the limits of the State were quite different from those which it has at present.

The following extract from the enabling act gives the original limits:

That the following shall be the boundaries of the said State of Iowa, to wit: Beginning at the mouth of the Des Moines River at the middle of the Mississippi; thence by the middle of the channel of that river to a parallel of latitude passing through the mouth of the Mankato, or Blue Earth River; thence west along the said parallel of latitude to a point where it is intersected by a meridian line, seventeen degrees and thirty minutes west of the meridian of Washington City; thence due south to the northern boundary line of the State of Missouri; thence eastwardly following that boundary to the point at which the same intersects the Des Moines River; thence by the middle of the channel of that river to the place of beginning. (Twenty-eighth Congress, second session.)

On December 28, 1846, an act was passed changing the boundaries of the State and giving it its present limits.

The following extract from the act defines the boundaries as at present constituted:

Beginning in the middle of the main channel of the Mississippi River, at a point due east of the middle of the mouth of the main channel of the Des Moines River; thence up the middle of the main channel of the said Des Moines River, to a point on said river where the northern boundary line of the State of Missouri, as established by the constitution of that State, adopted June twelfth, eighteen hundred and twenty, crosses the said middle of the main channel of the said Des Moines River; thence westwardly along the said northern boundary line of the State of Missouri, as established at the time aforesaid, until an extension of said line intersect the middle of the main channel of the Missouri River, to a point opposite the middle of the main channel of the Big Sioux River, according to Nicollet's map; thence up the main channel of the said Big Sioux River, according to said map, until it is intersected by the parallel of forty-three degrees and thirty minutes north latitude; thence east along said parallel of forty-three degrees and thirty minutes, until said parallel intersect the middle of the main channel of the Mississippi River; thence down the middle of the main channel of said Mississippi River, to the place of beginning.

## MINNESOTA.

The Territory of Minnesota was organized on March 3, 1849, and originally comprised the portion of the former Territory of Iowa, outside of the limits of the present State of Iowa, extending east to the west boundary line of Wisconsin. The terms of the act creating this Territory, so far as they relate to its boundary, are as follows:

All that part of the territory of the United States which lies within the following limits, to wit: Beginning in the Mississippi River, at the point where the line of forty-three degrees and thirty minutes of north latitude crosses the same; thence running due west on said line, which is the northern boundary of the State of Iowa, to the northwest corner of the said State of Iowa; thence southerly, along the western boundary of said State, to the point where said boundary strikes the Missouri River; thence up the middle of the main channel of the Missouri River to the mouth of the White Earth River; thence up the middle of the main channel of the White Earth River to the boundary line between the possessions of the United States and Great Britain, to Lake Superior; thence along the western boundary line of said State

of Wisconsin to the Mississippi River; thence down the main channel of said river to the place of beginning." (Thirtieth Congress, second session.)

Minnesota was admitted as a State on May 11, 1858, with the same boundaries which it has at present. These are given in the enabling act as follows:

Beginning at the point in the center of the main channel of the Red River of the North where the boundary line between the United States and the British Possessions crosses the same; thence up the main channel of said river to that of the Bois des Sioux River; thence up the main channel of said river to Lake Traverse; thence up the center of said lake to the southern extremity thereof; thence in a direct line to the head of Big Stone Lake; thence through its center to its outlet; thence by a due south line to the north line of the State of Iowa; thence east along the northern boundary of said State to the main channel of the Mississippi River; thence up the main channel of said river, and following the boundary line of the State of Wisconsin until the same intersects the Saint Louis River; thence down said river to and through Lake Superior, on the boundary line of Wisconsin and Michigan, until it intersects the dividing line between the United States and the British Possessions; thence up Pigeon River, and following said dividing line, to the place of beginning.

## KANSAS.

The Territory of Kansas was organized on May 30, 1854, from a part of Missouri Territory. The following clause from the act of organization defines its limits:

SECTION 19. All that part of the territory of the United States included within the following limits, except such portions thereof as are hereinafter expressly exempted from the operations of this act, to wit: Beginning at a point on the western boundary of the State of Missouri, where the thirty-seventh parallel of north latitude crosses the same; thence west on said parallel to the eastern boundary of New Mexico; thence north on said boundary to latitude thirty-eight; thence following said boundary westward to the east boundary of the Territory of Utah, on the summit of the Rocky Mountains; thence northward on said summit to the fortieth parallel of latitude; thence east on said parallel to the western boundary of the State of Missouri; thence south with the western boundary of said State to the place of beginning, be, and the same is hereby, created into a temporary government by the name of the Territory of Kansas.

A portion of this Territory was given up to Colorado at the time of its formation in 1861. (*Vide* Colorado, p. 123.)

Kansas was admitted into the Union on January 29, 1861, with its present boundaries, which are thus defined in the enabling act:

The said State shall consist of all the territory included within the following boundaries, to wit: Beginning at a point on the western boundary of the State of Missouri, where the thirty-seventh parallel of north latitude crosses the same; thence west on said parallel to the twenty-fifth meridian of longitude west from Washington; thence north on said meridian to the fortieth parallel of latitude; thence east on said parallel to the western boundary of the State of Missouri; thence south with the western boundary of said State to the place of beginning.

## NEBRASKA.

The Territory of Nebraska was formed on May 30, 1854, from the northwestern part of Missouri Territory. Its limits, as originally constituted, are defined as follows in the act of organization:

Beginning at a point in the Missouri River where the fortieth parallel of north latitude crosses the same; thence west on said parallel to the east boundary of the Territory of Utah, on the summit of the Rocky Mountains; thence on said summit northward to the forty-ninth parallel of north latitude; thence east on said parallel to the western boundary of the Territory of Minnesota; thence southward on said boundary to the Missouri River; thence down the main channel of said river to the place of beginning, be, and the same is hereby, created into a temporary government by the name of the Territory of Nebraska. (Thirty-third Congress, first session.)

This area was reduced in 1861 by the formation of the Territories of Colorado and Dakota. (*Vide* Colorado, p. 123, and Dakota, p. 121.)

The State of Nebraska was admitted on March 1, 1867.

Its limits are defined as follows in the enabling act:

That the said State of Nebraska shall consist of all the territory included within the following boundaries, to wit: Commencing at a point formed by the intersection of the western boundary of the State of Missouri with the fortieth degree of north latitude; extending thence due west along said fortieth degree of north latitude to a point formed by its intersection with the twenty-fifth degree of longitude west from Washington; thence north along said twenty-fifth degree of longitude to a point formed by its intersection with the forty-first degree of north latitude; thence west along said forty-first degree of north latitude to a point formed by its intersection with the twenty-seventh degree of longitude west from Washington; thence north along said twenty-seventh degree of west longitude to a point formed by its intersection with the forty-third degree of north latitude; thence east along said forty-third degree of north latitude to the Keyapaha River; thence down the middle of the channel of said river, with its meanderings, to its junction with the Niobrara River; thence down the middle of the channel of said Niobrara River, and following the meanderings thereof, to its junction with the Missouri River; thence down the middle of the channel of said Missouri River, and following the meanderings thereof, to the place of beginning. (Thirty-eighth Congress, first session.)

In 1870 an act was passed to redefine a portion of the boundary between Nebraska and the Territory of Dakota, the pertinent portion of which is as follows:

That so soon as the State of Nebraska, through her legislature, has given her consent thereto, the center of the main channel of the Missouri River shall be the boundary line between the State of Nebraska and Territory of Dakota, between the following points, to wit: Commencing at a point in the center of said main channel, north of the west line of section twenty-four in township twenty-nine north, of range eight east of the sixth principal meridian, and running along the same to a point west of the most northerly portion of fractional section seventeen, of township twenty-nine north, of range nine east of said meridian, in the State of Nebraska, as meandered and shown by the plats and surveys of said sections originally made and now on file in the General Land Office. (Forty-first Congress, second session.)

In 1882 an act was passed transferring to this State from Dakota a small area lying between the Keyapaha River and the forty-third parallel of latitude. The following is the act in question:

*Be it enacted,* * * * That the northern boundary of the State of Nebraska shall be, and hereby is, subject to the provisions hereinafter contained, extended so as to include all that portion of the Territory of Dakota lying south of the forty-third parallel of north latitude and east of the Keyapaha River and west of the main channel of the Missouri River. (Forty-seventh Congress, first session.)

## DAKOTA.

The Territory of Dakota was organized on March 2, 1861, from parts of Minnesota and Nebraska Territories. The following from the act of organization defines its original limits:

All that part of the territory of the United States included within the following limits, namely: Commencing at a point in the main channel of the Red River of the North, where the forty-ninth degree of north latitude crosses the same; thence up the main channel of the same, and along the boundary of the State of Minnesota to Big Stone Lake; thence along the boundary line of the said State of Minnesota to the Iowa line; thence along the boundary line of the State of Iowa to the point of intersection between the Big Sioux and Missouri Rivers; thence up the Missouri River and along the boundary line of the Territory of Nebraska to the mouth of the Niobrara or Running Water River; thence following up the same, in the middle of the main channel thereof, to the mouth of the Kehapaha or Turtle Hill River; thence up said river to the forty-third parallel of north latitude; thence due west to the present boundary of the Territory of Washington; thence along the boundary line of Washington Territory to the forty-ninth degree of north latitude; thence east along said forty-ninth degree of north latitude to the place of beginning be, and the same is, hereby organized into a temporary government by the name of the Territory of Dakota. (Thirty-sixth Congress, second session.)

In 1863 the Territory of Idaho was formed, its area having been taken from Washington, Dakota, and Nebraska. (*Vide* Idaho, p. 127.) In 1882 a small area was transferred to Nebraska. (*Vide* Nebraska, above.)

The following description, compiled from the act relating to Dakota and other Territories formed from its area, gives its present limits:

The east boundary is the main channel of the Red River from the forty-ninth parallel southward to Big Stone Lake; from the center of that lake to its outlet; thence by a due south line to the parallel of latitude 43° 30′; thence west on this parallel until it strikes the Big Sioux River; thence down the mid channel of the Big Sioux River to its mouth. The south boundary is the main channel of the Missouri River until it intersects the forty-third parallel of latitude; thence it follows the forty-third parallel of latitude westward to the twenty-seventh degree of longitude. The west boundary is the twenty-seventh degree of longitude, and the north boundary is the forty-ninth parallel of latitude.

## MONTANA.

The Territory of Montana was organized May 26, 1864, from a portion of Idaho. Its limits, which have been changed but slightly, are given in the following extract from the organizing act:

That all that part of the territory of the United States included within the limits to wit: Commencing at a point formed by the intersection of the twenty-seventh degree of longitude west from Washington with the forty-fifth degree of north latitude; thence due west on said forty-fifth degree of latitude to a point formed by its intersection with the thirty-fourth degree of longitude west from Washington; thence due south along said thirty-fourth degree of longitude to its intersection with the forty-fourth degree and thirty minutes of north latitude; thence due west along said forty-fourth degree and thirty minutes of north latitude to a point formed by its intersection with the crest of the Rocky Mountains; thence following the crest of the Rocky Mountains northward till its intersection with the Bitter Root Mountains; thence northward along the crest of said Bitter Root Mountains to its intersection with the thirty-ninth degree of longitude west from Washington; thence along said thirty-ninth degree of longitude northward to the boundary line of the British possessions; thence eastward along said boundary line to the twenty-seventh degree of longitude west from Washington; thence southward along said twenty-seventh degree of longitude to the place of beginning, be, and the same is hereby created into a temporary government by the name of the Territory of Montana. (Thirty-eighth Congress, first session.)

In 1873, Congress, under the erroneous impression that a portion of Dakota remained west of Wyoming, and adjoining Montana, passed an act to attach it to Montana. As, however, no such detached area could by any possibility have existed, the compilers of the Revised Statutes sought to give the act effect by shifting a portion of the southern boundary of Montana from the parallel of 44° 30′ to the continental watershed, thereby reducing Montana's area. The following is the act referred to:

AN ACT to readjust the western boundary of Dakota Territory.

That all that portion of Dakota Territory lying west of the one hundred and eleventh meridian of longitude which, by an erroneous definition of the boundaries of said Territory by a former act of Congress, remains detached and distant from Dakota proper some two hundred miles, be and the same is hereby attached to the adjoining territory of Montana. (Forty-second Congress, third session.)

The boundaries of Montana are as follows: Beginning at the intersection of the twenty-seventh meridian of longitude with the boundary line between the United States and the British possessions, it follows said meridian south to the forty-fifth parallel of latitude, thence west on this parallel to the thirty-fourth meridian, south on the thirty-fourth meridian to the point where that meridian intersects the continental watershed, thence westward and northwestward following the line of the continental watershed and the summit of the Bitter Root range, to its intersection with the thirty-ninth meridian, thence north on the thirty-ninth meridian to the boundary line between the United States and British possessions and east on that boundary line to the point of beginning.

## WYOMING.

Wyoming was organized as a Territory on July 25, 1868, from territory previously comprised in the Territory of Idaho. Its limits, which are the same as originally constituted, are defined in the following clause from the act creating the Territory:

That all that part of the United States described as follows: Commencing at the intersection of the twenty-seventh meridian of longitude west from Washington with the forty-fifth degree of north latitude, and running thence west to the thirty-fourth meridian of west longitude, thence south to the forty-first degree of north latitude, thence east to the twenty-seventh meridian of west longitude, and thence north to the place of beginning, be, and the same is hereby, organized into a temporary government by the name of the Territory of Wyoming. (Fortieth Congress, second session.)

## COLORADO.

Colorado was organized as a Territory on February 28, 1861, with the limits which it has at present, being made from portions of Utah, New Mexico, Kansas, and Nebraska.

On August 1, 1876, it was admitted as a State.

The following clause from the enabling act gives its limits:

AN ACT to enable the people of Colorado to form a constitution and State government, and for the admission of such State into the Union on an equal footing with the original States.

SEC. 2. That the said State of Colorado shall consist of all the territory included within the following boundaries, to wit: Commencing at a point formed by the intersection of the thirty-seventh degree of north latitude with the twenty-fifth degree of longitude west from Washington; extending thence due west along said thirty-seventh degree of north latitude to a point formed by its intersection with the thirty-second degree of longitude west from Washington; thence due north along said thirty-second degree of west longitude to a point formed by its intersection with the forty-first degree of north latitude; thence due east along said forty-first degree of north latitude to a point formed by its intersection with the twenty-fifth degree of longitude west from Washington; thence due south along said twenty-fifth degree of west longitude. (Thirty-eighth Congress, first session.)

## NEW MEXICO.

New Mexico was organized as a Territory on December 13, 1850. Its original area formed a part of the region transferred by Mexico to the United States by the treaty of Guadalupe Hidalgo and by Texas. It was subsequently enlarged by the Gadsden Purchase. (*Vide* pp. 21 and 22.) The formation of Colorado Territory in 1861 and of Arizona in 1863 reduced its area to its present limits. (*Vide* Colorado, above, and Arizona, p. 125.)

The following clause from the act creating the Territory gives its original limits:

SECTION 2. And be it further enacted, That all that portion of the territory of the United States bounded as follows: Beginning at a point in the Colorado River, where the boundary line with the Republic of Mexico crosses the same; thence eastwardly with the said boundary line to the Rio Grande; thence following the main channel of said river to the parallel of the thirty-second degree of north latitude; thence east with said degree to its intersection with the one hundred and third degree of longitude west of Greenwich; thence north with said degree of longitude to the parallel of thirty-eighth degree of north latitude; thence west with said parallel to the summit of the Sierra Madre; thence south with the crest of said mountains to the thirty-seventh parallel of north latitude; thence west with said parallel to its intersection with the boundary line of the State of California; thence with said boundary line to the place of beginning—be, and the same is hereby, erected into a temporary government by the name of the Territory of New Mexico. (Thirty-first Congress, first session.)

The present boundaries of New Mexico are as follows: Beginning at the point of intersection of the one hundred and third meridian of longitude west of Greenwich with the thirty-seventh parallel of latitude, running thence south to its point of intersection with the thirty-second parallel of latitude; thence west on this parallel to its intersection with the Rio Grande; thence southerly down the main channel of the Rio Grande to its point of intersection with the boundary line between the United States and Mexico; thence with this boundary to its intersection with the thirty-second meridian of longitude; thence north along this meridian to the thirty-seventh parallel of latitude, and so along that parallel to the point of beginning.

## UTAH TERRITORY.

Utah was organized on September 9, 1850, from territory acquired from Mexico by the treaty of Guadalupe-Hidalgo. Its limits originally extended from the eastern boundary of California to the Rocky Mountains, and from the thirty-seventh to the forty-second parallel. This area was reduced by the formation, in 1861, of the Territories of Nevada (*vide* p. 125) and Colorado (*see* p. 123), and in 1864 and 1866 by the extension eastward of the limits of the State of Nevada (*vide* p. 126).

The following is an extract from the act creating the Territory:

All that part of the territory of the United States included within the following limits, to wit: Bounded on the west by the State of California, on the north by the Territory of Oregon, and on the east by the summit of the Rocky Mountains, and on the south by the thirty-seventh parallel of north latitude, be, and the same is hereby, created into a temporary government, by the name of the Territory of Utah.

The present boundaries of Utah are as follows: Commencing with the intersection of the forty-second parallel of latitude with the thirty-fourth

meridian of longitude, running thence south on this meridian to the forty-first parallel of latitude, thence east on this parallel to the thirty-second meridian of longitude, thence south on this meridian to its intersection with the thirty-seventh parallel of latitude, thence west upon this parallel of latitude to its intersection with the thirty-seventh meridian of longitude, thence north on this meridian to its intersection with the forty-seventh parallel of latitude, thence east on the forty-seventh parallel of latitude, to the point of beginning.

## ARIZONA.

Arizona was organized as a Territory on February 24, 1863. Its area was formerly comprised in the Territory of New Mexico. In 1866 a portion of it was cut off and given to the State of Nevada. (*Vide* Nevada, below.) The following clause from the act creating it gives its limits as originally constituted:

That all that part of the present Territory of New Mexico situate west of the line running due south from the point where the southwest corner of the Territory of Colorado joins the northern boundary of the Territory of New Mexico to the southern boundary line of said Territory of New Mexico, be, and the same is hereby, erected into a temporary government by the name of the Territory of Arizona. (For limits of the piece cut off and added to Nevada, see that State.)

The present boundaries of Arizona are as follows: Beginning at the point of intersection of the thirty-seventh parallel of latitude with the thirty-second meridian of longitude; thence south along this meridian to its intersection with the boundary line between the United States and Mexico; thence with this boundary to the Colorado River; thence up the middle of the main channel of the Colorado River to its point of intersection with the thirty-seventh meridian of longitude; north on this meridian to its intersection with the thirty-seventh parallel; and eastward along the thirty-seventh parallel to the point of beginning.

## NEVADA.

Nevada, as originally constituted on March 2, 1861, was formed from territory taken from Utah. Its western boundary was made to conform to the eastern boundary of California (*vide* California, p. 129); its northern boundary was, as now, the forty-second parallel; the eastern was the meridian of 39°; and the southern the parallel of 37°. By the enabling act the eastern limit was extended to the thirty-eighth meridian. It was admitted as a State October 31, 1864, with above limits as modified

## OREGON.

Oregon Territory was organized August 14, 1848. The grounds of our title to its area are obscure. In treating with Great Britain for the establishment of our northern boundary west of the Rocky Mountains this region was claimed on three grounds—that of discovery and occupation, the Louisiana purchase, and cession from Spain. On which of these grounds we succeeded in having the boundary established on the forty-ninth parallel will never be ascertained, and is of little moment.

The Territory as originally established extended from the forty-second to the forty-ninth parallel, and from the Pacific Ocean to the crest of the Rocky Mountains, with boundaries defined in the organizing act, as follows:

All that part of the territory of the United States which lies west of the summit of the Rocky Mountains, north of the forty-second degree of north latitude, known as the Territory of Oregon, shall be organized into and constitute a temporary government by the name of the Territory of Oregon. (Thirtieth Congress, first session.)

In 1853 the Territory was reduced by the formation of Washington Territory (*vide* Washington, below), and on February 14, 1859, it was admitted as a State with its present boundaries. These are defined below in an extract from the State constitution:

Beginning one marine league at sea due west from the point where the forty-second parallel of north latitude intersects the same; thence northerly, at the same distance from the line of the coast lying west and opposite the State, including all islands within the jurisdiction of the United States, to a point due west and opposite the middle of the north ship channel of the Columbia River; thence easterly to and up the middle channel of said river, and where it is divided by islands, up the middle of the widest channel thereof, and in like manner up the middle of the main channel of Snake River to the mouth of the Owyhee River; thence due south to the parallel of latitude forty-two degrees north; thence west along said parallel to the place of beginning, including jurisdiction in civil and criminal cases upon the Columbia River and Snake River concurrently with States and Territories of which those rivers form a boundary in common with this State. But the Congress of the United States, in providing for the admission of this State into the Union, may make the said northern boundary conform to the act creating the Territory of Washington.

## WASHINGTON TERRITORY.

This was organized March 2, 1853, from a part of Oregon Territory. Its limits, as originally constituted, were as given in the following clause from the act of Congress creating it:

That from and after the passage of this act, all that portion of Oregon Territory lying and being south of the forty-ninth degree of north latitude, and north of the middle of the main channel of the Columbia River from its mouth to where the forty-sixth degree of north latitude crosses said river, near Fort Walla Walla, thence with said forty-sixth degree of latitude to the summit of the Rocky Mountains, be organ-

ized into and constitute a temporary government by the name of the Territory of Washington. (Thirty-second Congress, second session.)

In 1859, on the formation of the State of Oregon, the residue of the Territory of Oregon, being the portion lying east of the present limits of the State, extending thence to the crest of the Rocky Mountains, was added to Washington. This area, with the part of Washington lying east of its present limits, was included in Idaho on the formation of that Territory in 1863.

The present boundaries of Washington Territory are as follows: Beginning on the coast at the mouth of the Columbia River; following up the main channel of the Columbia River to its point of intersection with the forty-sixth parallel of latitude; thence east on the forty-sixth parallel to the Snake River; thence down the main channel of the Snake River to the mouth of the Clearwater; thence north on the meridian which passes through the mouth of the Clearwater to the boundary line between the United States and the British possessions; thence west with that boundary line to the Pacific.

## CALIFORNIA.

California was admitted to the Union on September 9, 1850. Its area was taken from territory acquired from Mexico by the treaty of Guadelupe-Hidalgo. Its limits, as defined in the State constitution, are as follows:

Commencing at the point of intersection of forty second degree of north latitude with the one hundred and twentieth degree of longitude west from Greenwich, and running south on the line of said one hundred and twentieth degree of west longitude until it intersects the thirty-ninth degree of north latitude; thence running in a straight line in a southeasterly direction to the river Colorado, at a point where it intersects the thirty-fifth degree of north latitude; thence down the middle of the channel of said river to the boundary line between the United States and Mexico as established by the treaty of May 30, 1848; thence running west and along said boundary line to the Pacific Ocean, and extending therein three English miles; thence running in a northwesterly direction, and following the direction of the Pacific coast, to the forty-second degree of north latitude; thence on the line of said forty-second degree of north latitude to the place of beginning. Also all the islands, harbors, and bays along and adjacent to the Pacific coast.

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# ADVERTISEMENT.

[Bulletin No. 14.]

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The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the Second, Third, Fourth, and Fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Mineral Resources and Dictionary of Altitudes, the Survey has no copies of any of its publications for gratuitous distribution.

## ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

## MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, and VIII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt., U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

## ADVERTISEMENT.

The following are in press, viz:

IX. Brachiopods and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. ix, 338 pp. 35 pl.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 56 pl.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. —, — pp. 46 pl.

The following are in preparation, viz:

I. The Precious Metals, by Clarence King.

Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.

Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

Lake Bonneville, by G. K. Gilbert.

Sauropoda, by Prof. O. C. Marsh.

Stegosauria, by Prof. O. C. Marsh.

### BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 14 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining value of Troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. A Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8° 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

Numbers 1 to 6 of the Bulletins form Volume I, and numbers 7 to 14 Volume II. Volume III is not yet complete.

The following are in press, viz:

15. On the Mesozoic and Cenozoic Paleontology of California, by Dr. C. A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the higher Devonian Faunas of Ontario County, New York, by J. M. Clarke. 1885. 8°. — pp. 3 pl. Price — cents.

17. On the Development of Crystallization, etc., by Arnold Hague and J. P. Iddings. 1885. 8°. — pp. Price — cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Dr. C. A. White. 1885. 8°. — pp. 3 pl. Price — cents.

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. — pp. Price — cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. — pp. 1 pl. Price — cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. — pp. 5 pl. Price — cents.

# ADVERTISEMENT.

## STATISTICAL PAPERS.

A fourth series of publications having special reference to the mineral resources of the United States is contemplated.

Of that series the first has been published, viz:

Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

The second volume of this series, Mineral Resources 1883 and 1884, is in preparation and will soon be put to press.

Correspondence relating to the publications of the Survey, and all remittances, which must be by POSTAL NOTE OR MONEY ORDER, should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
*Washington, D. C.*

WASHINGTON, D. C., *April* 30, 1885.

DEPARTMENT OF THE INTERIOR

# BULLETIN

OF THE

# UNITED STATES

# GEOLOGICAL SURVEY

## No. 14

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

# ELECTRICAL AND MAGNETIC PROPERTIES

OF THE

# IRON-CARBURETS

BY

CARL BARUS and VINCENT STROUHAL

# PREFACE.

Early in 1881 one of us submitted to Prof. G. F. Becker, geologist in charge of the Division of the Pacific, a brief digest of the facts showing the singular adaptability of the electrical properties of the iron-carburets for the classification of these products, with the request that permission be given us for the extension of the work in the laboratory of the Geological Survey. Professor Becker at once indorsed the project enthusiastically, and owing to his advocacy our proposal shortly after received the assent of the Hon. Clarence King, then Director of the Survey,—given with the proviso that the electrical researches be not prosecuted to such an extent as to occupy us exclusively.

Divers special investigations and routine duties, together with the labor involved in providing for the organization of a physical laboratory, prevented us from giving the furtherance of the proposed researches the attention necessary. Nevertheless, data of a varied character continually accumulated, while the scope and the conception of our general problem enlarged at an unexpectedly rapid rate. The publication of our results in some connected form, therefore, urged itself more and more seriously upon us.

About a year ago our plan was effectually encouraged by Prof. F. W. Clarke, chief chemist of the United States Geological Survey.

The experiments to be discussed in this memoir have occupied our available time during the last five years. Notices, more or less complete, have appeared abroad from time to time in places not readily accessible to the public. Some of the papers it was deemed necessary to publish in German with considerable fullness. But all English publication has been purposely delayed, not only because we desired to reduce the results originally expressed in terms of the German standards to the more current and now legal denominations of ohm, volt, etc.,[1] but principally because it seemed expedient for facility of comparison to refer all our data to the uniform temperature, zero centigrade. This

[1] In making this reduction the legal equation, 1 ohm = 1.06 S. U., was made use of in all chapters with the exception of III and IV, the results of which were reduced at an earlier date and when 1 ohm = 1.05 S. U. appeared to be nearer the truth. This, however, is of no serious significance, because in these chapters the relative values of resistance are alone of interest. The absolute accuracy of the reduced values is of course immediately dependent on the absolute accuracy of the German standards (Siemens) at our disposal.

premised an accurate knowledge of the relation between electrical conductivity and temperature for iron, for steel in different states of temper, and for cast iron, and required excessively tedious labor.

The results in Chapter I on the electrical temperature-coefficient of iron-carburets present an unexpected range of variation, and thus possess intrinsic interest.

In Chapter II we investigate and discuss the conditions of the operation of tempering. This chapter is fundamental. Such facts as essentially sustain the argument underlying the whole of the present work are, therefore, emphasized with a larger number of experimental data than would otherwise be necessary.

In Chapter III we attempt to throw new light on the laws set forth in Chapter II by following them into their ulterior consequences. With the aid of certain allied electrical properties of alloys and of malleable cast iron, the nature of the phenomenon of hardness as presented by steel is discussed from every available physical and chemical point of view, within the scope of the present purposes.

In Chapters IV, V, and VI, the method for the accurate definition of hardness, and the scheme of operations for tempering developed in Chapter II, are consistently applied to analogous magnetic phenomena. The nature of the dependence of magnetization on the three independent variables of cylindrical rods, viz: carburation, ratio of dimensions, hardness, for given conditions of structure, is carefully discussed and in part graphically represented. Rules are finally given for the treatment of magnets, such that exceptionally great retentiveness, both as regards the hurtful effects of temperature and time and of shocks, may be conveniently attained with the least available sacrifice of magnetization.

We may add that a supplementary Bulletin is now in preparation, in which the very remarkable annealing effect of high temperatures (400°..1000°) will be magnetically discussed, and furthermore the degree of approximate coincidence between the physical state (of the necessarily linear rod) characterized by the unique maximum of magnetizability and the physical state of maximum density of steel, will be determined. That these states must be found very nearly coincident, our present results permit us to predict.

In Chapter VII, finally, we endeavor to generalize upon the foregoing results, as a whole; to restate the fundamental laws with greater accuracy and breadth of scope than was possible in the earlier chapters; and, finally, to deduce from all a method for the physical definition of iron-carburets.

Minor discussions, the relevancy of which does not justify their immediate introduction into the chapters proper, are frequently introduced as addenda.

We desire in this place particularly to emphasize that throughout the present work the terms "*thermo-electrically positive*" and "*thermo-electrically negative*" are to be understood in the way defined by the original

investigators, Seebeck,[2] Becquerel,[3] Hankel;[4] *i. e.*, with reference to the series arranged thus:

$$-\text{Bi}.... \text{Cu}... \text{Fe}.... \text{Sb}+,$$

an acceptation which we believe to be general on the Continent.[5] In England the above terms are received in a sense which is precisely the opposite of this; that is, with reference to the thermo-electric series,[6] arranged thus:

$$+\text{Bi}.... \text{Cu}... \text{Fe}.... \text{Sb}-.$$

Of the two methods of designation, the latter is obviously the more logical and consistent, as will readily be seen, for instance, if the galvanic and the thermo-element be analogously described. And if we refrained from embodying the latter acceptation in this memoir, we have done so merely because of the great liability to error encountered in changing the sense of every thermo-electric expression and diagram, as well as the signs of all of the many thermo-electric data. Isolated constructions are too apt to be overlooked, and this in a way completely to mar the drift of the context. But the English reader will find no difficulty in making this change of sign for himself in any set of thermo-electric data which may interest him. To avoid all misconception, moreover, we give the direction of current in each essential case.

Much of the work was done abroad in Professor F. Kohlrausch's laboratory. It is a pleasant duty which permits us to extend to Professor Kohlrausch, in this place, our grateful acknowledgments, not only for the kindly interest with which he regarded the progress of the experiments throughout their extent, but for much valuable advice by which the papers have materially profited.

We desire to mention, in conclusion, that work done by us conjointly, if published in German, is to be put under S. and B.; if in English, under B. and S., conformably with an original agreement.

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UNITED STATES GEOLOGICAL SURVEY,
*Washington, December* 1, 1884.

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[2] Seebeck: Gilb. Ann., LXXIII, pp. 115 and 430, 1823.

[3] Becquerel: Ann. de Chim. et de Phys., XLI, p. 353, 1829.

[4] Hankel: Pogg. Ann., LXII, p. 197, 1844.

[5] Cf. Wiedemann: Lehre v. d. Elektricität, II, p. 248 et seq., 1883. Mousson: Physik, III, p. 381 et seq., 1875. Jamin: Cours de Physique, 2d ed., T. III, p. 42, 1869.

[6] Cf. Jenkin: Electricity and Magnetism, p. 175 et seq., 1880. Maxwell: Electricity and magnetism, 2 ed., Vol. I, p. 338–9, 1881.

## SUPPLEMENTAL.

The principal contents of the supplementary Bulletin referred to in the above preface may expediently be placed on record here:

1. The inter-dependence of density, electrical conductivity, maximum of permanent magnetization, maximum of permanent hardness of linear cylindrical steel rods, under all permissible conditions of temperature. The location of the unique magnetic maximum.

2. The bearing of temperature and time of exposure on the temper-value of the color of the oxide-films.

3. The internal structure of tempered steel.

4. Certain synthetic methods of production of iron-carburets, available for the construction of the classification-diagram.

B. & S.

WASHINGTON, *March* 27, 1885.

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# INTRODUCTION.

To avoid ambiguity and vagueness we will state here, at the outset, that the considerations presented in this memoir apply to that species of hardness which can be imparted to steel by a process of tempering; *i. e.*, by a process of sudden cooling from a given temperature in red heat, accompanied by a stated amount of subsequent annealing. Such an operation, regarded as a method in virtue of which the metal acted upon experiences a particular and characteristic kind of strain, must be accompanied by a series of physical effects peculiar to itself. It is true that the conditions which determine the efficacy of tempering will themselves have to be accurately defined. Even under favorable circumstances these are not thoroughly within the observer's control, or, at best, are attainable with extreme difficulty. All results are, therefore, distorted by a variety of anomalies. But in the great number of data investigated a certain normal effect clearly appears, and it is to this that our remarks apply. In other words, we have been led in an unavoidably laborious way to the results of theoretically perfect tempering.

With regard to the hardness of steel, we cannot as yet rigidly discriminate between the effect to be ascribed to a change in the quality of carburation and that which is due to the strain simultaneously experienced; *i. e.*, the numerical value of the importance of the said effects has as yet remained undeterminable, though much has been done toward assigning to each its respective limit. But, *a priori*, in so far as the character of this strain-effect will enable us satisfactorily to interpret a majority if not all of the attendant physical phenomena, we are temporarily justified in giving the mechanical postulate preference. At all events it is frequently permissible to abstract from the chemical change altogether, and to speak of tempering a rod to glass-hardness, just as we do of magnetizing it to saturation, for instance. Both operations may be said to be such that more of a given kind of strain (hardness in the one case and magnetism in the other) is originally imparted to the rod than it is able, *of itself*, to maintain. A part of this disappears, while a residue, characteristic of the nature of the rod and of the physical circumstances under which it exists, is permanently retained. This consideration suggests some analogies between hardness and magnetism. Irrespective of its practical importance and from a purely physical point of view, tempering possesses an intrinsic interest inferior only to magnetization, or indeed comparable with it. Of the enormous stress which the former operation enables us to apply, the steel rod, in virtue of a peculiar internal structure, retains a phenomenal amount. This great intensity of available strain we may cause to disappear as gradually

or to reappear as often as we please. Conformably with the change of mechanical state, the extreme values of the electrical and magnetic properties of steel comprehend a similarly extended interval. We are thus enabled to follow these, in the case of the same material, through a range of variation that is enormous, and must throw new light on their intrinsic nature.

Another point deserves brief mention here. If we conceive a theoretically perfect process of tempering to glass-hardness, and suppose it applied to rods identical in every respect, the results must necessarily be identical. In other words, the type of internal structure presented by the first would be reproduced in all subsequent rods. Take the comparatively simple but important case of cylindrical rods: The density of the elementary cylindrical shells, coaxial with the respective cylinders, would be the same for the same radius; the distribution of density along similar radii would follow the same law. If now the rods be identically annealed the results must still be identical, and thus we arrive eventually at identical soft states. It follows, therefore, that for rods of the same dimensions (*diameter*) and composition the magnetic properties are immediately comparable as functions of hardness.

This we are no longer at liberty to assume when the (cylindrical) rods otherwise identical, have different diameters. For this reason alone the rods, though tempered alike, *i. e.*, subjected to the same operation, are to be regarded as structurally dissimilar. It is in place here to present some concise meaning for the term "structure" as applied to hard steel rods. We, therefore, define it as the law of the variation of density encountered on a passage along any radius of a given (cylindrical) steel rod from its axis to its circumference. This premised, it is not absolutely impossible (however improbable) that rods of different diameters, identically tempered, may, *cæteris paribus*, show identical structures. That such a unique condition of things cannot be postulated is obvious at once. Indeed, the manner of variation of the law of distribution of density, as we pass from rods of a given thickness to rods of any other thickness, is not even conjecturable, and we cannot, therefore, consistently compare the magnetic intensities of rods of different diameters as functions of hardness. In the most favorable case we would encounter in our passage from rod to rod, besides the difference of hardness, something of the nature of a change of parameter, expressing the necessary difference of internal structure referred to. In other words, it will be shown in the sequel that with a given thickness, a characteristic family of magnetic curves may be obtained, referred to hardness and length of rod as independent variables. We infer that such a family exists for each thickness, and that our passage from one given diameter to another is expressible by a difference in the value of a parametric constant.

We have mentioned magnetic phenomena in particular, because it is here that the evidence derived from data illustrating the influence of structure is singularly cogent.

# THE ELECTRICAL AND MAGNETIC PROPERTIES OF THE IRON-CARBURETS.

By CARL BARUS and VINCENT STROUHAL.

## CHAPTER I.

### ON THE RELATION BETWEEN ELECTRICAL CONDUCTIVITY AND TEMPERATURE IN THE CASE OF STEEL IN DIFFERENT STATES OF HARDNESS, OF WROUGHT IRON, AND OF CAST IRON.

#### STEEL.

*Earlier results.*—The experiments made thus far on the resistance-effect of temperature[7] scarcely permit us to distinguish in this particular between iron and steel. In fact, the data in hand for the said coefficients lie within about the same interval, 0.004 to 0.005, both for the one metal and the other. We will give as examples some of the best results of earlier observers.

According to Mousson,[8] the electrical resistance $s_t$ at the temperature $t$ is expressible in terms of $s_o$, the corresponding quantity at zero, by an equation with a single constant:

$$s_t = s_o\,(1+0.00421\times t)$$

for iron;

$$s_t = s_o\,(1+0.00406\times t) \text{ to } s_t = s_o\,(1+0.00424\times t)$$

for steel.

Benoit,[9] who carried his researches to much higher degrees and through much greater intervals of temperature, finds:

$$s_t = s_o\,(1+0.00452\cdot t+0.000\,005\,83\cdot t^2)$$

in case of iron;

$$s_t = (1+0.00498\cdot t+0.000\,007\,35\cdot t^2)$$

in case of soft steel.

Nevertheless we felt justified in believing that these researches in case of a substance which, like steel, is capable of existing in so many enormously different states of hardness, which presents such an incomparably wide range of values of electrical conductivity, are far from complete; we regarded the assertion warrantable that steel cannot, under all circumstances, possess a temperature-coefficient of electrical resistance so little different from that of iron. Indeed, we had reasons to

[7]For a very complete digest of the experimental results in question, see G. Wiedemann, Lehre von der Elektricität, I, p. 502–510, 1882.

[8]Mousson: G. Wiedemann, l. c., p. 507.

[9]Benoit: Comptes. Rend., LXXVI, p. 342. 1873. Carl's Rep., IX, p. 55, 1873.

presume that between the resistance of a metal in any given physical state and the corresponding temperature-coefficient, a relation would in all probability be discoverable, and that an example of such a relation could be most satisfactorily studied with steel itself.

*Analogous behavior of alloys.*—Some facts lending favor to this view may be cited. It is known that alloys of two metals vary in marked degree as regards their electrical conductivity with the relative quantity of a second or foreign metallic ingredient added to the original metal. Great numbers of valuable results on these relations have been gathered by Matthiessen and Vogt.[10] Thus, for instance, the alloy silver-platinum, according to these observers, shows the following electrical behavior: If $\lambda_t$ be the (relative) electrical conductivity of a given silver-platinum alloy at $t°$; if volume-percents of platinum alloyed to silver be understood; and if the wires be supposed hard drawn; then,

Platinum, 0 per cent. $\lambda_t = 100 - 0.38287 \cdot t + 0.000\,984\,8 \cdot t^2$;
Platinum, 2.51 per cent. $\lambda_t = 31.640 - 0.03936 \cdot t + 0.000\,036\,42 \cdot t^2$;
Platinum, 5.05 per cent. $\lambda_t = 18.031 - 0.01395 \cdot t + 0.000\,011\,82 \cdot t^2$;
Platinum, 19.65 per cent. $\lambda_t = 6.696 - 0.00221 \cdot t + 0.000\,001\,393 \cdot t^2$.

If we have reference to a small interval of temperature only, these results may be more perspicuously given by the aid of a single (mean) coefficient calculated from the observed conductivities. More simply, therefore,

Platinum, 0 per cent. $\lambda_t = 100\ (1 - 0.00383 \cdot t)$;
Platinum, 2.5 per cent. $\lambda_t = 31.6\ (1 - 0.00124 \cdot t)$;
Platinum, 5.1 per cent. $\lambda_t = 18.0\ (1 - 0.00077 \cdot t)$;
Platinum, 19.7 per cent. $\lambda_t = 6.7\ (1 - 0.00033 \cdot t)$.

Herefrom it is obvious that the temperature-coefficient of an alloy varies continuously and in a pronounced way with its electrical conductivity. This becomes all the more strikingly apparent when the results are represented graphically.

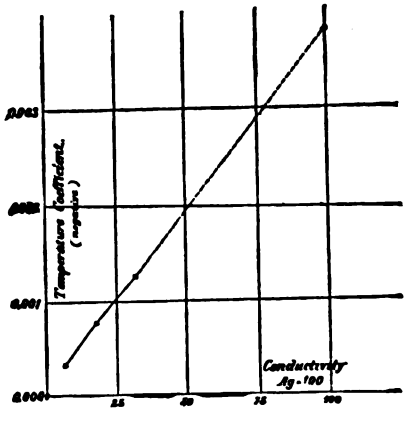



FIG. 1.—Electrical conductivity and temperature-coefficient of silver-platinum alloys.

[10] Matthiessen and Vogt: Pogg. Ann., CXXII, p. 19, 1864.

Similar results, but less complete, and therefore superfluous here, we ourselves obtained with German silver. But, to give an instance: the specific resistance, $s_t$, of the German silver wire of C. Vogel, Berlin, was found to be ($s_t$ given in $cm/cm^2$, microhm),

$$s_t=16.4\ (1+0.00064\cdot t),$$

whereas for that of W. Siemens, Berlin,

$$s_t=39.0\ (1+0.000.9\cdot t).$$

Now we shall show elsewhere that the analogy between the electrical behavior of steel in different states of hardness, and that of alloys of two metals in different proportions is, from certain points of view, very complete. It follows, therefore, that a relation similar to the one set forth is to be anticipated in case of steel, such that the variation of electrical resistance produced by tempering must be accompanied by a similarly continuous but inverse change of the values of the temperature-coefficient of steel. Our experiments fully corroborate this.

*Resistance-temperature equation.*—Before proceeding further, however, we may remark that it would be impossible in case of steel to adhere to the very desirable formula

$$s_t=s\ (1+at+bt^2),$$

throughout. Consistency, therefore, induces us to assume a linear relation in all cases. The reasons are these: the relation between resistance and temperature-coefficient to be investigated necessarily and primarily excludes all possibility of permanent change in the material itself. When glass-hard steel is examined, the interval of temperature within which the rod may be heated or cooled without experiencing perceptible annealing is very limited. The same is true of moderately annealed steel. We are as yet ignorant of the effects of this kind which may possibly also be produced by cooling below zero. Hence it is indispensably necessary to vary the temperature of glass-hard rods only so much as is just called for, if the measurements are to furnish satisfactorily reliable data. Should an annealing effect occur, the results would not of course be comparable. Now the available interval of temperature is fully large enough for the linear formula. It is insufficiently so in the other case; for in the quadratic formula it is possible to change the coefficient of $t$ to quite an appreciable extent without producing marked variation in the values of $s_t$, if only an appropriate and compensatory change be made in the coefficient of $t^2$, simultaneously. Hence the simple formula

$$s_t=s_0\ (1+\alpha t)$$

has been made use of throughout, where $t$ was permitted to vary within the interval 10° to 35° only.

*Method of measurement.*—The changes of temperature, and therefore also those of resistance, being very slight, amounting only to a few hundredths ohm, it was necessary to make the electrical measurements with extreme accuracy. For this purpose the method of Matthiessen and Hockin, which we have repeatedly used, proved to be admirably

serviceable. A few modifications had to be introduced. In the place of the two needles originally employed for obtaining contacts at fixed distances apart, and which if submerged in water would have introduced the disturbing effects of loose contacts, two fine copper wires were tightly wound around the extreme parts of the steel rod under experiment, and fastened in a way that made sliding impossible. The rod was then alternately placed in two vessels containing cold and warm water respectively, care being taken not in any way to strain the copper circuit wires. The short-circuiting through distilled water from one fine copper wire to the other is obviously negligible.

The temperature of the cold bath was approximately that of the room, and very constant; that of the warm bath varied during a single measurement not more than a few tenths of a degree. Temperature being read before and after the resistance measurement, the mean value could be regarded as a very satisfactory datum. The steel rod examined was placed first in the cold, then in the warm, and finally again in the cold bath. The mean of the measurements 1 and 3 was therefore to be combined with 2, 4 and 6 with 5, etc. The degree of approximate equality of the results of these distinct sets of observations, and the agreement between the measurements 1, 3, 4, 6, etc., give a good estimate of the accuracy of the work.

*Material. Resistance-value of oxide-tints.*—The material used was that employed in all our researches, English "silver" steel in rods 0.15 cm. in diameter. After having been suddenly chilled in great numbers, certain of them were annealed by the electrical current, in this way: Having carefully polished the hard rod, it was introduced into the circuit of a dynamo-electric machine. As the temperature of the wire increased the oxide-tints appeared in a strikingly perfect manner, and it was only necessary to regulate the current cautiously and stop the operation at a given moment to obtain any oxide-tint desired almost uniformly over the whole length of the wire. The observations of this paragraph therefore give in an approximate way the temper-value of the oxide-tint appearing in air on a bright hard steel rod, in terms of electrical resistance.

*Results.*—The following table, 1, contains a perspicuous comparison of the data of observation as obtained with six steel rods in different states of temper. For the diameter $2\rho$ (cm) of the rod and the length $l$ (cm) direct measurement showed the resistance $w$ (ohm) at the temperature $t°$ ($C.$). Also the resistance $W$ (ohm) at $T°$. This is sufficient for the calculation of $w_0$ for 0° and $a$, the required coefficient. The known dimensions then enable us to deduce the specific resistance $s$ (cm/cm² 0°). Finally, we give the specific gravity $\Delta$ of the wires, calculated for the known dimensions and the known weight. Our object in computing this constant was primarily that of checking the values for the sections of our rods as measured by the aid of the microscope. But they furnish a satisfactory corroboration of the general increase of dens-

ity of steel on passing from the hard to the soft state, conformably with the results of C. Fromme:

TABLE 1.—*Temperature-coefficient of steel.*

| Rod. | $2\rho$, $l$, $\Delta$ | $w$ | $t$ | $W$ | $T$ | $w_0$ | $\alpha$ | $s$ |
|---|---|---|---|---|---|---|---|---|
| | cm. | ohm. | | ohm. | | ohm. | | microhm. |
| Glasshard | $2\rho$= 0.151 | 0.04523 | 10.0 | 0.04685 | 32.9 | 0.04450 | 0.00161 | 45.7 |
| | $l$=17.52 | 20 | 10.2 | 59 | 29.5 | ..... | 160 | ..... |
| | $\Delta$= 7.56 | 24 | 10.4 | ..... | ..... | ..... | ..... | ..... |
| Annealed light-yellow. | $2\rho$= 0.148 | 0.03107 | 10.2 | 0.03297 | 35.5 | 0.03030 | 0.00250 | 28.9 |
| | $l$=17.98 | 06 | 10.3 | 65 | 32.2 | ..... | 238 | ..... |
| | $\Delta$= 7.57 | 10 | 10.6 | ..... | ..... | ..... | ..... | ..... |
| Annealed yellow | $2\rho$= 0.150 | 0.02782 | 10.9 | 0.02950 | 33.2 | 0.02698 | 0.00278 | 26.3 |
| | $l$=18.17 | 84 | 11.0 | 22 | 29.6 | ..... | 279 | ..... |
| | $\Delta$= 7.54 | 81 | 11.0 | ..... | ..... | ..... | ..... | ..... |
| Annealed blue | $2\rho$= 0.149 | 0.02043 | 10.0 | 0.02191 | 32.5 | 0.01978 | 0.00327 | 20.5 |
| | $l$=16.77 | 47 | 10.1 | 75 | 29.8 | ..... | 332 | ..... |
| | $\Delta$= 7.56 | 45 | 10.2 | ..... | ..... | ..... | ..... | ..... |
| Annealed light-blue. | $2\rho$= 0.148 | 0.01948 | 9.3 | 0.02097 | 31.6 | 0.01881 | 0.00357 | 18.4 |
| | $l$=17.58 | 46 | 9.5 | 70 | 27.7 | ..... | 363 | ..... |
| | $\Delta$= 7.66 | 47 | 9.7 | ..... | ..... | ..... | ..... | ..... |
| Soft | $2\rho$= 0.146 | 0.01690 | 9.7 | 0.01850 | 32.5 | 0.01625 | 0.00428 | 15.9 |
| | $l$=17.13 | 94 | 9.9 | 27 | 29.4 | ..... | 419 | ..... |
| | $\Delta$= 7.69 | 96 | 10.0 | ..... | ..... | ..... | ..... | ..... |

If for $\alpha$ we take mean values, and compare these with the degrees of hardness of steel, characterized by $s$, we obtain more clearly:

TABLE 2.—*Oxide-tint, specific electrical resistance and electrical temperature-coefficient of steel.*

| | $s$ $\frac{\text{cm}}{\text{cm}^2}$ 0° | $\alpha$ |
|---|---|---|
| | microhm. | |
| Glasshard | 45.7 | 0.00161 |
| Annealed light yellow | 28.9 | 244 |
| Annealed yellow | 26.3 | 280 |
| Annealed blue | 20.5 | 330 |
| Annealed light blue | 18.4 | 360 |
| Soft | 15.9 | 423 |

*The electrical temperature-coefficient of steel, therefore, decreases in proportion as its specific resistance or its degree of hardness increases, at a rate diminishing as we pass from soft to hard steel.*

The following little table interpolated from the above values, for practical purposes, may be put on record here:

TABLE 3.—*Specific electrical resistance and electrical temperature-coefficient of steel. Practical table.*

| $s$ | $\alpha$ | $s$ | $\alpha$ | $s$ | $\alpha$ | $s$ | $\alpha$ |
|---|---|---|---|---|---|---|---|
| $\frac{\text{cm}}{\text{cm}^2}$ 0° | | $\frac{\text{cm}}{\text{cm}^2}$ 0° | | $\frac{\text{cm}}{\text{cm}^2}$ 0° | | $\frac{\text{cm}}{\text{cm}^2}$ 0° | |
| microhm. | | microhm. | | microhm. | | microhm. | |
| 10 | 0.0050 | 21 | 0.0033 | 32 | 0.0022 | 43 | 0.0017 |
| 11 | 48 | 22 | 32 | 33 | 21 | 44 | 17 |
| 12 | 46 | 23 | 31 | 34 | 21 | 45 | 16 |
| 13 | 44 | 24 | 29 | 35 | 21 | 46 | 16 |
| 14 | 42 | 25 | 28 | 36 | 20 | 47 | 15 |
| 15 | 41 | 26 | 27 | 37 | 19 | 48 | 15 |
| 16 | 39 | 27 | 27 | 38 | 19 | 49 | 15 |
| 17 | 38 | 28 | 26 | 39 | 19 | 50 | 15 |
| 18 | 36 | 29 | 25 | 40 | 18 | 60 | 13 |
| 19 | 35 | 30 | 24 | 41 | 18 | 70 | 13 |
| 20 | 34 | 31 | 23 | 42 | 17 | 80 | 12 |

## WROUGHT IRON.

*Digest of earlier results.*—The relation between electrical resistance and temperature in case of iron has been studied by a large number of observers, among whom Lenz, Becquerel, Arndtsen, Mousson, and others, are to be mentioned. But the most comprehensive and accurate data are unquestionably those given by Matthiessen and Vogt.[11] These will therefore be discussed here.

Matthiessen and Vogt assume the quadratic formula

$$\lambda=\lambda_0-at+bt^2$$

for $\lambda$, the conductivity of any given metal, relatively to hard-drawn silver ($\lambda_0=100$). Their results for $a$ and $b$, in case of fifteen samples of iron, conveniently abbreviated, are contained in Table 4.

TABLE 4.—*Electrical temperature-coefficient and electrical conductivity of divers samples of iron.*

| Description of sample. | No. | $a$ | $b$ | $\lambda_0$ |
|---|---|---|---|---|
| Electrotype iron; Nos. 2 and 4 ignited in hydrogen and in air, respectively | 1 | 0.512 | 0.00129 | (16.810)[12] |
| | 2 | 0.519 | 134 | (16.810)[12] |
| | 3 | 0.514 | 132 | (16.810)[12] |
| | 4 | 0.509 | 127 | (16.810)[12] |
| Drawn iron wire, analyzed chemically | 5 | 0.473 | 112 | 15.712 |
| | 6 | 0.472 | 112 | 15.640 |
| | 7 | 0.449 | 102 | 14.294 |
| | 8 | 0.453 | 112 | 12.132 |
| Iron wires of different degrees of carburation | 9 | 0.463 | 109 | 14.723 |
| | 10 | 0.418 | 092 | 10.666 |
| | 11 | 0.404 | 092 | 9.921 |
| | 12 | 0.397 | 091 | 8.449 |
| Piano-forte wire | 13 | 0.425 | 092 | 13.293 |
| Watchspring | 14 | 0.340 | 063 | 8.568 |
| Commercial iron wire | 15 | 0.428 | 090 | 18.774 |

For the sake of facilitating a comparison of these results with our own, we reduced them, as nearly as possible, to absolute values of $s\frac{cm}{cm^2}$ 0° microhm, by accepting for "silver hard," for which Matthiessen and Vogt put $\lambda=100$,

$$s=1.574.$$

Moreover, the values have been arranged, commencing with pure iron, in the order of the values for resistance, the coefficient of quadratic $t$ being discarded and only linear $d$ introduced. The interpretation to be given to "$\alpha$ interpolated" will be explained presently.

[11] Matthiessen and Vogt: Pogg. Ann., CXVIII, p. 431, 1863.

[12] Probable value for pure iron, hard, deduced from the observations with impure metal, from an inspection of the respective temperature-coefficients.

TABLE 5.—*Specific electrical resistance and electrical temperature-coefficient of different kinds of iron.*

| Description of sample. | $s\frac{cm}{cm^2}0°$ | $\alpha$ observed. | $\alpha$ interpolated. |
|---|---|---|---|
| | *microhm.* | | |
| Nos. 1 to 4 | 9.4 | 0.0052 | 0.0052 |
| No. 5 | 10.0 | 47 | 50 |
| No. 6 | 10.1 | 47 | 50 |
| No. 9 | 10.7 | 46 | 49 |
| No. 7 | 11.1 | 45 | 48 |
| No. 15 | 11.4 | 43 | 47 |
| No. 13 | 11.8 | 42 | 46 |
| No. 8 | 13.0 | 45 | 44 |
| No. 10 | 14.8 | 42 | 41 |
| No. 11 | 15.9 | 40 | 40 |
| No. 12 | 16.7 | 40 | 37 |
| No. 14 | 18.4 | 34 | 36 |
| Steel, soft | 15.9 | 42 | 40 |

*Resistance-temperature equations of iron and of steel.*—The first line of these data, showing the mean value of a number of observations with pure iron, is the most reliable. If this be added to our results for steel (Table 2), the whole series of results may be compared graphically, by representing specific resistance, $s$, as abscissa temperature-coefficient, $\alpha$, as ordinate. The points lie satisfactorily on a locus of definite character, which in its turn may be utilized for purposes of interpolation. In this way the last column of the foregoing table ("$\alpha$ interpolated") has been deduced, the temperature-coefficient for each value of specific resistance for the sample of iron cited being selected. The discrepancies or differences between observed and calculated results are not larger than a combination of observations made on the great variety of material by different observers, together with the wide range of possible errors incident to all, would lead us to anticipate. Even the position of soft steel with reference to the curve is, in every respect, satisfactory. It is in this way, finally, that the practical results in Table 3 were derived.

Benoit[13] finds the following relations between resistance and temperature for soft iron and soft steel, respectively:

$$s_t=0.1272\ (1+0.00452\cdot t+0.0000058\cdot t^2),$$

and

$$s_t=0.1149\ (1+0.00498\cdot t+0.0000074\cdot t^2),$$

$$(Hg=1 \quad m \mid \overline{mm}^2).$$

These results referred to microhms and cm/cm² are

$$s=12.1 \qquad \alpha=0.00452$$

for iron, and

$$s=10.9 \qquad \alpha=0.00498$$

for steel. Both sets of values are in good accordance with our graphic representation. We obtain by means of this:

For $s=12.1$, the value $\alpha=0.00457$,

and

For $s=10.9$, the value $\alpha=0.00485$.

[13] Benoit: Comptes rend., LXXVI, p. 342, 1873. Wiedemann, l. c., p. 525. The small value $s=10.9$ obtained by Benoit for soft steel is remarkable and exceptional.

## CAST-IRON.

*Anticipative results.*—Of particular interest in connection with this discussion is the behavior of the most highly carburized of commercial iron-products, cast-iron. Observations for pairs of the electrical magnitudes under consideration, for this material, are not in hand. Elsewhere we will describe certain experiments, made in some number, with reference to the thermo-electric and galvanic properties of cast-iron. Here we need only mention, that the specific resistance of this metal is very decidedly larger than the largest attainable results for glass-hard steel. If, therefore, a relation[14] between electrical conductivity and electrical temperature-coefficient of the kind premised, actually exists, then this latter quantity must, in like manner, be smaller than the smallest results arrived at in case of steel.

To test this inference, three samples were selected from our supply of cast-iron rods, Nos. 13, 14, 15, each about 25 cm. in length, and their resistance in the soft or thoroughly annealed state (annealed at red heat and cooled very slowly) determined at different convenient temperatures. But this resistance, in view of the comparatively large section of the said rods (about 0.4 $cm^2$) being as small as 0.004 ohms, the measurement had to be made even with greater precaution than was necessary in the case of steel.

*Method of measurement.*—The method of measurement was, however, essentially identical in the two sets of experiments, being Matthiessen and Hockin's. The terminal wires of copper, wherever necessary insulated by glass tubes, were wrapped around and soldered to the cast-iron rods; these, together with the insulated terminals and a good thermometer, introduced into a wide glass tube. Through the latter, closed at both ends by suitably perforated corks, securing tubes of influx and efflux, vapor at the boiling point of the respective liquids continually circulated. Methyl alcohol vapor, and steam were especially convenient. The tube itself, thickly jacketed with felt and cloth, showed a desirably constant temperature throughout the course of the work. All these precautions were necessary, for the ulterior reason of excluding possible thermo-electric action at the junctions of cast-iron and copper. Such currents are otherwise readily evoked in intensity sufficient utterly to vitiate the accuracy of the measurements.

*Results.*—The following table will show that the experiments conducted with this care were satisfactorily successful. Here $a$ and $b$ denote the sides of the approximately rectangular section of the cast-iron rods; $l$, the effective length in the resistance measurements. From an inspection of the resulting errors, the linear relation assumed to exist

[14] A detailed discussion regarding the electrical effects of the strain accompanying hardness and of carburation, respectively, will be given in Chapter III.

between resistance and temperature within the interval 0°—100°, will be found to be acceptable.

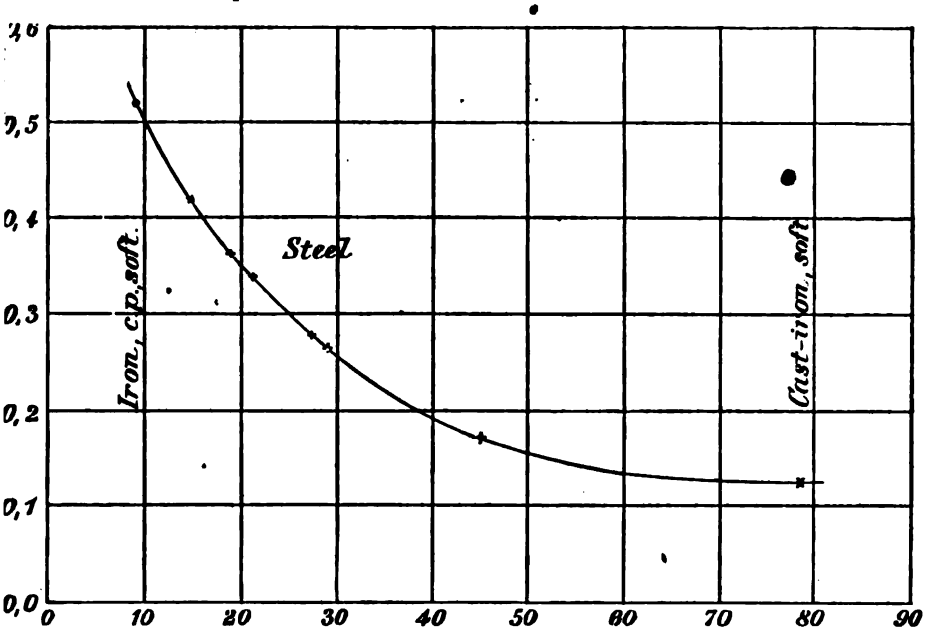



FIG. 2.—Diagram of the relation between specific electrical resistance and temperature-coefficient for wrought iron, for steel, and for cast iron.

The results show that the mean temperature-coefficient of cast iron falls very fairly on what may be considered a prolongation of the locus obtained for iron and steel (see figure), or that the electrical temperature-coefficients of iron-carburets, in general, may be regarded as a definite function of the respective specific resistances:

TABLE 6.—*Temperature-coefficient of cast-iron.*

| Rod No. | Constants. | $t$ | $w$ | $t$ mean. | $w$ observed. | $w$ calculated. | Diff. | $s$ | $\alpha$ | $s$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | *cm.* | *C.* | *ohm.* | | | | | *ohm.* | | *microhm.* |
| 13 | $a$= 0.640 | 23.8 | 0.003749 | 23.5 | 0.003743 | 0.003743 | 0 | 0.003637 | 0.00124 | 76.0 |
| | $b$= 0.656 | 23.2 | 3738 | | | | | | | |
| | $l$=20.10 | 67.2 | 3938 | 67.3 | 3941 | 3941 | 0 | | | |
| | | 67.5 | 3943 | | | | | | | |
| | | 99.4 | 4093 | 99.3 | 4085 | 4085 | 0 | | | |
| | | 99.3 | 4077 | | | | | | | |
| 14 | $a$= 0.643 | 22.8 | 3839 | 22.8 | 3837 | 3829 | 8 | 3712 | 138 | 76.2 |
| | $b$= 0.642 | 22.8 | 3835 | | | | | | | |
| | $l$=20.10 | 67.8 | 4041 | 69.5 | 4051 | 4068 | —17 | | | |
| | | 71.2 | 4061 | | | | | | | |
| | | 99.5 | 4235 | 99.5 | 4235 | 4224 | 11 | | | |
| | | 99.5 | 4235 | | | | | | | |
| 15 | $a$= 0.646 | 20.0 | 4095 | 18.7 | 4099 | 4102 | — 3 | 4008 | 126 | 83.3 |
| | $b$= 0.647 | 17.8 | 4095 | | | | | | | |
| | $l$=20.10 | 18.3 | 4108 | | | | | | | |
| | | 66.0 | 4347 | 66.0 | 4347 | 4341 | 6 | | | |
| | | 66.0 | 4347 | | | | | | | |
| | | 100.0 | 4500 | 100.0 | 4509 | 4513 | — 4 | | | |
| | | 100.0 | 4490 | | | | | | | |
| | | 100.0 | 4536 | | | | | | | |

## DEDUCTIONS.

*Analogous behavior of alloys and of iron-carburets.*—The data contained in the above tables throw some light on the probability of an analogy between alloys generally and iron carburets, inasmuch as they show a certain similarity of behavior in both kinds of products. It is not impossible that we have here in hand examples of a general law; in other words, it may be plausibly argued that whenever the properties of a primary metal are altered by addition of various quantities of a second substance (metallic or non-metallic) alloyed thereto, that then the known variation of electrical resistance is invariably accompanied by a corresponding variation of the electrical temperature-coefficient—in such a way that an increment of the former corresponds to a decrement of the latter in accordance with some fundamental relation. In the case of ordinary alloys, small quantities of a second metal are alloyed to the original material, producing the known electrical effect. In the case of steel the process of tempering is the cause of a change in the quality of carburation, so that in a highly tempered bar more *combined* or electrically active carbon is, as it were, alloyed to iron than in one of inferior temper or in a soft rod. Hence the corresponding electrical effect. But it is well to waive this subject here to discuss it more satisfactorily in another chapter.

*Temperature-coefficient and volume.*—We shall show elsewhere[15] that for steel at least, and possibly for all non-electrolyzed conductors, the specific resistance may, with some fitness, be regarded as a volume-function only. Probably a similar remark may also be made with reference to the temperature-coefficient of steel, and it would appear that with this metal, the most promising of the available means for the study of the bearing of specific volume on specific resistance and temperature-coefficient, is furnished us. Clausius[16] was the first to call attention to the approximate proportionality of the resistance of most pure metals with their absolute temperatures. If we accept Mathiessen's general relation between resistance and temperature for pure metals:

$$s_t = s_o\,(1+at+\delta t^2), \qquad a=0.003824, \qquad \delta=0.000\,001\,26$$

and put

$$\frac{ds_t}{dt}=\frac{1}{273},$$

we find that at about 60° C. the said proportionality is accurate. There would be some propriety, therefore, in considering this state of the metals in question as a normal state, and the corresponding specific

[15] Chapter III.

[16] Clausius: Pogg. Ann., CIV, p. 650, 1858. Auerbach (Wied. Ann., VIII, p. 479, 1879) has endeavored to explain this circumstance, and also to interpret the exceptional value encountered in case of iron.

resistance as their normal resistance. It may be remarked, in passing, that the temperature to which *soft* steel must be cooled in order (theoretically) to annul its resistance coincides very nearly with the absolute zero of temperature.

## ADDENDUM.

### STATEMENT OF A RESISTANCE METHOD FOR THE MEASUREMENT OF HEAT-CONDUCTIVITY.

The success of the above application of Matthiessen and Hockin's method for the accurate measurement of very small increments of resistance, has suggested to us the availability of the same method in determining the necessary data for the calculation of heat-conductivity.

The subject of heat-conductivity has of late been largely discussed, especially in German literature. In most of the cases new methods have been proposed and employed. Our object herewith is to offer an experimental modification of the well-known method due to Biot, but first applied by Depretz,[17] which we believe has certain practical advantages.

Depretz heats the ends of a straight rod of uniform section to different constant temperatures $T$ and $t$ ($T>t$). After the stationary thermal condition has set in, $t_1$, $t_2$, $t_3$, the temperature of any three consecutive right sections, at the same distance $l$ apart, respectively, are related as follows:

$$e^{\mu l}+e^{-\mu l}=(t_1+t_3):t_2 \quad \ldots\ldots\ldots \quad (1)$$

where, moreover, $\mu$ for rods of the same section and of the same external conductivity is, under the assumption of constant $l$, inversely proportional to the square root of heat-conductivity. Suppose, however, that instead of measuring the temperatures at three consecutive equidistant sections, we propose to determine the resistances of three consecutive equal lengths $l$ of the rod, after the thermal condition has become stationary. We have

$$dr=\frac{s}{q}(1+\alpha t)\,dx,$$

where $dr$ is the elementary resistance corresponding to the length $dx$, at the temperature $t$, $s$ the specific resistance of the material, $q$ its (uniform) section, $\alpha$ a given constant. In view of the steady thermal flow, we may write

$$dr=\frac{s}{q}[1+\alpha(Ce^{\mu x}+C'e^{-\mu x})]\,dx.$$

If this equation is integrated successively between the limits $l_2$ and $l_1$, $l_3$ and $l_2$, $l_4$ and $l_3$, where $l_2-l_1=l_3-l_2=l_4-l_3=l$, we obtain three equa-

[17] Depretz: Ann. d. chim. XXXVI, p. 422, 1827; Cf. Langberg, Pogg. Ann., LXVI, p. 1, 1845; Wiedemann and Franz, Pogg. Ann., LXXXIX, p. 497, 1853.

tions from which the constants $C$ and $C^1$ may be eliminated. The following relation results:

$$2n=e^{\mu l}+e^{-\mu l}=\frac{\frac{r_{21}}{r_o}-1+\frac{r_{43}}{r_o}-1}{\frac{r_{32}}{r_o}-1} \quad \ldots\ldots\ldots (2)$$

where $r_o$ is the resistance of the length $l$, at zero. Equation (2) might have been more elegantly derived indirectly from equation (1) above.

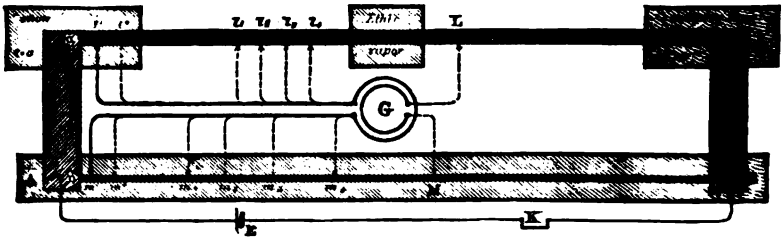



FIG. 3.—Diagram of a resistance-apparatus for measuring heat conductivity.

Suppose, now, that in connection with this result we use Hockin and Matthiessen's device of two corresponding sliding contacts in the manner indicated in the annexed diagram. Let

$$l''-l'=l_2-l_1=l_3-l_2=l_4-l_3=l$$

Let the points $m'$, $m''$, $m_1 \ldots . m_4$ on the wire $\delta e$ correspond to $l'$, $l''$, $l_1 \ldots . l_4$ in such a way that, if connection be made between any two of them with the prolonged terminals of a galvanoscope $G$, the needle of the latter will receive no additional impulse on momentarily closing the key $K$. Then we may write

$$2n=\frac{\frac{m_2-m_1}{m''-m'}-1+\frac{m_4-m_3}{m''-m'}-1}{\frac{m_3-m_2}{m''-m'}-1};$$

whence it follows that Depretz' method by application of Hockin and Matthiessen's device may be theoretically reduced to a simple *measurement of lengths.*

It is not our object here to go into any practical details.[18] But we may remark that hurtful thermo-currents may be reduced to a minimum by using a sliding contact at the points $l$ of a material thermo-electrically similar to the rod to be examined. Their effect would be that of changing the position of equilibrium of the needle of the galvanoscope, and they would not seriously influence the impulse given to it by momentarily closing $K$. Moreover, the ends, $L$ and $M$, of an independent, permanently closed bridge-wire may be so adjusted as to compensate the thermo-electric disturbance entirely (end $L$), and

[18] The compendious form of Wheatstone's Bridge, invented by Kohlrausch, suggests itself for these measurements.

yet not interfere with the measurement (end $M$). In this case it is not necessary to close $l' \ldots . l_4$ for a short time prior to closing $K$, but both may be closed momentarily, the latter contact a little before and a little after the particular one of the former, with reference to which the observation is made.

It is our intention to endeavor to apply a procedure of this kind for the purpose of investigating whether the abnormal diminution of electrical conductivity due to tempering (about 70 per cent.) is accompanied by a corresponding variation of heat-conductivity. The plan would be the same as that detailed elsewhere.[19]

[19] Strouhal and Barus, Wied. Ann., XI, p. 976, 1880; ibid., pp. 953–4, 977.

## CHAPTER II.

### ON THE CONDITIONS WHICH IN THE CASE OF STEEL ESSENTIALLY DETERMINE THE EFFICACY OF THE OPERATION OF TEMPERING; THE MEASUREMENT OF THE STATE OF HARDNESS OF STEEL.

### INTRODUCTORY REMARKS.

*Origin of the work.*—At the outset of the present series of experiments it was our object to subject the relation existing between the amount of magnetization which saturated steel rods can permanently retain, and their mechanical condition, particularly their state of hardness, to a new and rigid investigation. We were led to this undertaking by the results shown in a paper by Barus,[20] in which it appears that the electrical properties of steel—its thermo-electric power and specific resistance primarily—furnish a datum of singular sensitiveness for the hardness of this material. It therefore lay within our scope and purpose to invent a method for obtaining as many well-defined degrees of hardness between the glass hard or suddenly chilled state on the one hand, and the soft or thoroughly annealed state on the other, as would be practicable.

During the progress of the work, however, the phenomena attending the operation of tempering, as exhibited by the thermo-electric power and the specific resistances of the different stages of hardness of steel, began more and more to engross us, and eventually became of sufficient importance to occupy our attention wholly. Thus it was that a special research, though partaking of the nature of a digression and calling for a larger expenditure of time than had been allotted to this part of the projected series of experiments, became almost necessary. The data in hand throw new light on the conditions determining the temper of steel, and indeed enable us to discuss the whole subject perspicuously and from a general standpoint. These remarks will suffice to account for the origin, purpose, and disposition of the parts of the present chapter.

*Material used.*—The steel used in this work was of the kind known as "English silver-steel."[21] It came to our hands in the shape of rods, about 30 cm. long, varying in diameter between 0.03 cm. and 0.01 cm., drawn accurately cylindrical for the use of watchmakers. The rods were nominally identical in composition, and obtained from Cooks' Brothers, of Sheffield and Manchester. In view of the great complexity

[20] Barus, Phil. Mag. (5), VIII, pp. 341–68, 1879; Wied. Ann., VII, p. 338, 1879. Cf. Appendix to this Bulletin, p. 203.

[21] See Chapter VII.

and vagueness associated with the term steel, it appeared necessary to confine the operations to the given type of this material—an exceptionally favorable type, moreover, when considered with reference to the enormous interval of hardness comprehended between its glass-hard and soft states. Chemical analysis of this individual member of the infinite family of possible steels would have been more than useless, as will clearly appear from a perusal of the present series of papers as a whole. As a rule we draw our inferences from rods broken from a single longitudinally homogeneous sample only. The purely physical relation sought is thus investigated unaffected by secondary phenomena or distortions, while the material, as it were, is represented by a series of temporarily constant parameters. In the present chapter this method of research is suggested naturally by the experiments themselves, and satisfactory material is easily obtained. But in the later chapters on magnetism, where the necessity of using chemically and structurally identical rods is much more urgent, these essential conditions are often secured only with difficulty.

## APPARATUS FOR IMPARTING GLASS-HARDNESS TO STEEL.

In view of the great number of steel wires to be tempered, the construction of an apparatus by the aid of which the operation of sudden cooling could be expeditiously and conveniently carried out, and which would impart to the wires a uniformity of hardness throughout their length, was an essential requisite. The following machine answered the purpose satisfactorily:

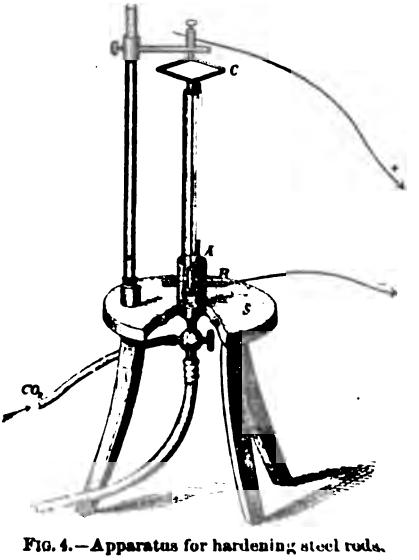



FIG. 4.—Apparatus for hardening steel rods.

In figure 4, *A* is a hollow cylinder 9 cm. long, of dense (box) wood, provided with a circular groove and slot so as to admit of its being securely fastened by a sort of bayonet-joint to a substantial tripod, or again removed, conveniently. Into the lower and wider part (3.0 cm. in diameter) of the aperture a closely-fitting faucet communicating with the water-mains by means of a hose, is inserted; into the upper opening of the same (1.5 cm. in diameter) there is fitted a glass tube of thin material and about 30 cm. long. This serves primarily as a protecting envelope for the steel wire stretched in its axis. Besides this gradually tapering canal, the box-wood cylinder is provided with a second perforation at right angles to the axis of the latter, in which a thick steel rod *B* (0.5 cm. in diameter) fits snugly.

The wire to be hardened is drawn tensely between two clamp-screws, in connection with the terminals of a powerful battery, in the following way: The lower clamp-screw possesses a longitudinal and a cross perforation. One end of the wire is fastened in the first of these holes by a lateral screw and then introduced into the wooden cylinder and attached glass tube, *A*, from below, whereupon the steel rod *B*, passed through the cross perforations in both cylinder and clamp-screw, and fastened by the vertical screw of the latter, puts the lower end of the wire in connection with one pole of the battery. As *B* may be rotated around its own axis and at the same time moved laterally, the wire may be satisfactorily centered. *A*, thus adjusted, is now attached to the tripod as above described, the faucet forced tightly in from below, and the upper end of the steel wire, which projects slightly out of the glass tube, grasped by a second clamp-screw. The latter forms a part of a peculiar spring *C*, in shape of a rhombus of very large horizontal but very short vertical diagonal. In this way a gentle tension, not so strong as to rupture the wire when red hot is constantly maintained, while the parts of the spring are thick enough to allow the passage of an intense galvanic current without becoming perceptibly heated. We have found that a wire symmetrically chilled and held tense in this way remains straight after the glass-hard temper has been imparted to it—an important desideratum. In order to centrally adjust the upper end of the wire, or to regulate the tension of the spring, the latter may be moved around and along a horizontal arm, which in its turn is similarly adjustable around a vertical post screwed to the tripod. To *C* and *B* the terminals of a powerful battery are suitably attached.

A current of dry carbonic acid gas continually circulating through the tube practically obviates the annoyance of oxidation during the heating to redness. To introduce this gas, the faucet is doubly perforated in the way devised by Senguerd. The larger of the canals is intended for the influx of water, the smaller for carbonic acid, and they are so disposed relatively to each other that if the one is open the other is necessarily closed. To manipulate the apparatus satisfactorily a considerable head of water is desirable. But even when these facilities are available,

the water, on opening the faucet, is apt to enter the tube with a squirt, chilling some parts of the wire before the main column advances, and in this way vitiating the otherwise attainable uniformity of glass-hardness. For this reason a second faucet (not shown in the figure) belonging to the hydrant was put into use. We operated in this way: The former faucet was first opened, producing no other effect than the interruption of the current of carbonic acid. Then one of us rapidly opened the second faucet, while the other, in due time, broke the galvanic circuit. As the glass tube was of comparatively small diameter, the water rushed into its interior, ascending as an unbroken column with great velocity and imparting to the wire the glass-hardness desired. According to Jarolimek[22] this rapidity of current is of paramount importance when the attainment of extreme degrees of hardness is the desideratum. In the case of quiet water a non-conducting envelope of steam is apt to inclose the wire, protecting it against instantaneous chilling. Such a layer would effectually be torn away by a very swift current, and cold water and wire remain in more intimate contact. We regarded the hypothesis, which Jarolimek believes to have verified by experiment, as plausible.

Glass tubes of thin walls were chosen, and breakage was therefore a rare occurrence. Of course we did not keep the wire in the red-hot state longer than appeared absolutely necessary.

The operation of disadjusting and drying the parts of the apparatus after each chilling proved to be a tedious annoyance. Nevertheless the efficiency of the apparatus may be said to have been demonstrated by the fact that after a little experience we were able to temper 50 to 60 wires during an interval of five hours. Of the total number of hard wires obtained (some 180), those were selected for the measurements which had been operated upon during our later and more expert manipulation. The ends were broken off and discarded, and only as much of the central part of each wire used as would warrant the assumption of uniformity of hardness throughout the lengths employed. The degree of homogeneity, moreover, admits of being specially tested, as will be explained below.

The battery used consisted of 20–30 large Bunsen cells, connected in series or in multiple arc in a way to correspond with the external resistance. In the latter case it is necessary to keep the partial circuits as nearly as possible alike. Otherwise a reverse current is apt to traverse one of them, gradually disintegrating the carbons.

## MEASUREMENT OF THERMO-ELECTRIC POWER.

*Thermo-element.*—The thermo-electric power of our wires was deduced from measurements of electromotive force and temperature, obtained by

[22]Jarolimek: Dingler's Jour., CCXXI, pp. 436, 518, 1876.

combining them thermo-electrically with the same given normal wire. Chemically pure silver, deposited galvanoplastically, fused, drawn, and softened, appeared to be the most desirable metal-of-reference for this purpose. Two samples of this were selected and compared. From reasons of a practical character, however, we found it expedient not to use these normals in the actual work. In the measurements, a copper wire of a given kind, which had frequently and very carefully been compared with the silver, was substituted for it, and the thermo-electric power steel-copper subsequently reduced to steel-silver, by calculation.

After testing many modifications, we adhered to the very efficient form of thermo-electric apparatus diagrammatically represented in figure 5. $S_1$ and $S_2$ are two doubly tubulated spherical receivers, of the

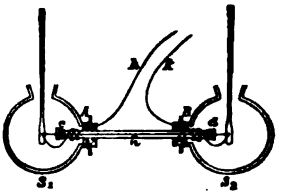


FIG. 5.—Form of thermo-element.

capacity 1 liter approximately. These were mounted on good non-conductors in such a way as to place the axes of the tubulures *A* and *B* in horizontal, the other two in vertical position. The former were provided with well-fitting corks, centrally perforated, so as to admit the glass tube *cd* (diam. 1 cm.) snugly. In this way the two receivers were held firmly together, and at distances apart adjustable at pleasure, thus adapting the arrangement for examination of a long or a short wire. Two small suitably-perforated corks, fitting the ends of the tube *cd*, gave to the wire an axial position within it. In this way the steel rods, exceedingly brittle and frail when in the state of glass-hardness, were adequately protected. Mention is still to be made of the terminals *h* and *k* of the apparatus. These were specially-selected samples of covered copper wire, as stated above. They passed through the large corks at *A* and *B*—in which they were cemented once for all—to the junctions at the center of the respective receivers. When a new rod was to be introduced, this was thrust through the tube *cd*, and the latter duly closed with the small corks, in the perforations of which the rod fitted tightly. Then the free ends of the terminals were connected with the respective ends of the steel rod, either by flat brass clamp-screws, or, where the temper permitted it, by soldering. The tube carrying the large corks was now in complete adjustment, and it was only necessary to insert these in the tubulures *A* and *B* of the receivers. One of the latter was then filled with water of the temperature of the room, the other with hot water. A woolen jacketing appropriately surrounding the hot receiver reduced the loss of heat by radiation to a minimum.

By the aid of two carefully calibrated thermometers, with their bulbs at the centers of the respective receivers, the temperature of these was read off. A small hole was drilled at $n$ in the tube $cd$ to allow for the expansion of the air heated by proximity to the hot water.

*Method of measurement.*—For the measurement of the thermo-electromotive force (expressed throughout in volts) a zero method was adopted. If $E$ (figure 6) be the compensating (one Daniell), $e$ the compensated element (the thermo-couple), $W$ the resistance of $AEB$, $w$ that of $AMB$, we shall have, when the current in $AeB$ containing the galvanometer is zero,

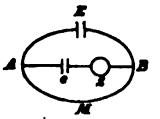



FIG. 6.—Disposition of thermo-electric apparatus.

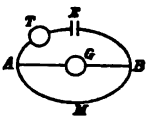



FIG. 7.—Apparatus for galvanometer-factor.

$$\frac{e}{E}=\frac{w}{W+w}.$$

In our experiments, in the most unfavorable cases,

$$\frac{w}{W}=\frac{5}{10000};$$

and hence, with sufficient accuracy for the present purpose we may put

$$\frac{e}{E}=\frac{w}{W}.$$

Both $w$ and $W$ were furnished by Siemens' rheostats. The resistances of the connecting wires and of the Daniell are negligible. $W$ could be increased to 30,000 ohms, $w$ diminished as far as 0.1 ohm.

In order to eliminate such discrepancies as would arise from variations of the Daniell, the electromotive force of this element was measured before and after each observation. It is known that this source of error is by no means negligible, and that it depends on the way in which the Daniell has been put together, and on the time of use. For the purpose in question, the terminals of a Wiedemann's galvanometer of known factor $A$ could be introduced into the circuit $EAMB$ with the aid of an appropriate key. If therefore the line $ASB$ is broken, the resistance $w$ excluded, we shall have a simple circuit $EAMB$ such that if $n$ be the deflection at the galvanometer

$$E=A\,Wn.$$

Usually $W$=20,000 ohms was chosen, as it was through this resistance, approximately, that the Daniell acted during the measurements with the zero method.

To determine the factor $A$ of the galvanometer we made use of a tangent-compass of known factor, $C$. This we calculated both from the dimensions of the coils and from voltametric observations. Figure 7

gives the disposition of apparatus diagrammatically, wherein $E$ is the Daniell, $T$ the tangent-compass, $G$ the mirror-galvanometer. Let $w$ be the resistance, $i$ the intensity of current in the shunt $A\ M\ B$, $W$ the resistance, and $I$ the current in $A\ G\ B$; then

$$IW=iw;$$

whence

$$\frac{I}{I+i}=\frac{w}{W+w}.$$

But by measurement with the tangent compass we get

$$I+i=C\,\mathrm{tg}\,\varphi\,[1+f(\varphi)],$$

and with the galvanometer, simultaneously, $I=An$, whence

$$An=\frac{w}{W+w}\,C\,\mathrm{tg}\,\varphi\,[1+f(\varphi)].$$

By a proper choice of $w$ and $W$, practically convenient deflections, both at the tangent compass and at the galvanometer, are obtainable. The determination of $A$ was frequently repeated.

*Essential details.*—The actual arrangement of apparatus as given in figure 8 differs from the diagram (figure 6) described above, only in that serviceably-disposed commutators and keys have been introduced into the partial circuits.

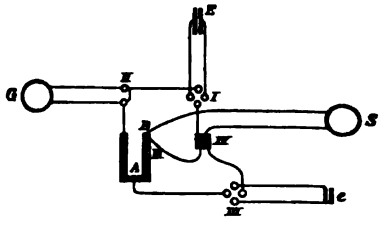



FIG. 8.—Details of thermo-electric apparatus.

The commutator $I$, inserted immediately after the Daniell, is used, in the first place, in determining the value of the electromotive force of this element from the double deflection of the mirror of the galvanometer $G$ put in circuit by the key $II$. In the second place, when manipulated in connection with another commutator, $III$, which changes the direction of current of the thermo-element, it adds very materially to the attainable accuracy by enabling the observer practically to eliminate the discrepancies due to extraneous thermo-currents. These result from an irregular distribution of temperature in the connections. We actually measure not

$$\frac{e}{E}=\frac{w}{W};\ \text{but}\ \frac{e+\varepsilon}{E+\varepsilon'}=\frac{w}{W},$$

where $\varepsilon$ and $\varepsilon'$ are the disturbing electromotive forces in question. Now $\varepsilon'$, which has its seat in the branch $EAMB$, is always negligible in comparison with $E$. A similar assumption, however, by no means applies to $\varepsilon$—*i. e.*, to the electromotive force which originates in the

branch *ASB*. This quantity, as our experiments have shown, very frequently reaches values amounting to a considerable part of $e$—indeed, when $e$ is small, $\varepsilon$ is directly comparable with it.

We therefore have

$$\frac{e+\varepsilon}{E}=\frac{w}{W}.$$

If both $e$ and $\varepsilon$ retained the same value before and after an observation there would result: Before commutation,

$$\frac{e+\varepsilon}{E}=\frac{w}{W};$$

after commutation,

$$\frac{e-\varepsilon}{E}=\frac{w^1}{W^1};$$

whence

$$\frac{e}{E}=\frac{1}{2}\left(\frac{w}{W}+\frac{w^1}{W^1}\right).$$

Now, although both $e$ and $\varepsilon$ do vary during the interval of an observation, the amount is small and the change of the former so nearly linear with the temperature $T$ of the warm receiver, that the mean of the electromotive forces $e$ may be regarded as coincident with the mean of the temperatures $T$. If the observations after commutation are rapidly made, which can easily be done because the approximate values of $W$ and $w$ are known from the first measurements, we may suppose $\varepsilon$ to have remained constant.[23] A mean of the two determinations therefore will very nearly eliminate $\varepsilon$.

Finally, reference is still to be made to the form of Weber's commutator *IV*, which serves the purpose of a key of special kind. The small mercury cups are so filled that the thermo-current is not closed until a moment after the partial current from the Daniell. When $w$ and $W$ are properly chosen, therefore, the needle of the galvanometer $S$ remains at rest. An exceedingly sensitive form of apparatus with an astatic needle, devised by Magnus and constructed by Sauerwald, was used here.

While one observer made the adjustments $w$ and $W$, the other read off the temperatures of the thermometers in the receivers at given signals.

*Calculation of constants.*—If $t$ and $T$ be the temperatures of the thermo-electric junctions, $e$ the corresponding electromotive force, we shall have generally[24]

$$e=a(T-t)+b(T^2-t^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Putting $T-t=x$, $T+t=u$, $e=y$,

$$y=ax+bxu \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Inasmuch as the number of observations was always greater than two,

[23] By commutating again we frequently convinced ourselves that this supposition was quite permissible. The values otained for the first and third positions of the commutators were so nearly identical that we could satisfactorily accept them as such.

[24] Avenarius: Pogg. Ann., CXIX, p. 406, 1863; ibid., CXLIX, p. 374, 1873; Tait, Trans. R. Soc. Edinb., XXVII, 1872-'73, p. 125. In this memoir the above equation is accepted merely as an empirical relation. Tait has discussed it theoretically.

for although $e$ is much more accurately measurable in the case of larg values of $T-t$, the observed value of $T$ will differ the more appreciabl from the true temperature of the hot junction of the thermo-element, t proportion as $T$ is greater than the temperature of the room in whic the observations are made.

By aid of the well-known formulæ developed by the method of lea squares, $a_o$ and $b_o$, of the thermo-couple copper-silver, were calculate from a large number of special observations.

By the same method, moreover, we derived the constants, $a^1$, $b^1$, f the elements steel-copper. To reduce from these the values $a$, $b$, whic hold for the couples steel-silver, we made use of a set of tables calculat thus: If $e$, $e^1$, $e_o$ correspond to $a$, $a^1$, $a_o$, we have

$$e=e^1-e_o,$$

where $e^1$ is dependent on the arguments $T$ and $t$. Now $e_o$ can be th expressed:

$$e_o=(a_oT+b_oT^2)-(a_ot+b_ot^2);$$

that is, as a difference between identical functions of the same arg ments $T$ and $t$. A table for

$$a_oz+b_oz^2$$

is therefore calculated once for all, from which for every combination $T$ and $t$ the quantity $e_o$, and therefore $e$, is easily obtained. After the observations, $e$, had been referred to silver, the constants $a$ and were deduced by the thermo-electric formulæ above given.

## MEASUREMENT OF ELECTRICAL CONDUCTIVITY.

The following is the method of calculation adopted:

$$\text{First position of commutator, } \frac{w+a}{\delta+b}=\frac{a_1}{b_1}=n_1;$$

$$\text{Second position of commutator, } \frac{w+b}{\delta+a}=\frac{b_2}{a_2}=n_2:$$

whence

$$w=n_1\delta+n_1b-a, \qquad w=n_2\delta+n_2a-b,$$

and therefore, if $\frac{1}{2}(n_1+n_2)=n$,

$$w=n\delta+(n-1)\frac{a+b}{2}-\frac{n_1-n_2}{2}\frac{a-b}{2}.$$

In the case of our bridge, at $t=10°$

$$\frac{a+b}{2}=0{\cdot}00194, \qquad \frac{a-b}{2}=-0{\cdot}00016.$$

Now, in so far as $n_1$ and $n_2$ are always nearly identical, a sufficient approximation for $w$ is furnished by the formula

$$w=n\delta+(n-1)\frac{a+b}{2} \quad \ldots\ldots\ldots \quad (1)$$

In this way the calculations were greatly simplified, since $n$ could be immediately obtained from Obach's[25] tables. A small table of our own contained the respective values of the term $(n-1)\frac{a+b}{2}$.

In a part of the measurements we obtained excellent results with the beautiful method due to Hockin and Matthiessen.

From this value of $w$, the length and the diameter $2\rho$—the latter dimension being determined microscopically—the specific resistance of the given wire at the temperature $t$ followed at once.

The normal resistance $\delta$ was given by a specially constructed étalon of heavy German silver wire, soldered to stout terminals of copper properly amalgamated. We were in possession of six of these, such that by suitable combinations, either in series or in multiple arc, resistances as high as 0·6 ohms and as low as $\frac{1}{60}$ ohm were available. We were thus able to keep the sliding contact near the middle of the bridge wire, and the value of the factor $(n-1)$ in equation (1) was therefore invariably small.

*Resistances at points of contact.*—In view of the very small resistances (0.5 to 0.05 ohms) to be measured, great care had to be taken to reduce the resistances at the places where the steel wires were inserted to a minimum. To obtain an estimate as to the value of the discrepancies produced in this way we made a determination of the resistance of a soft steel wire for three different methods of insertion. In the first of these the wires were firmly held between flat clamp-screws; in the second, the ends of the wires were covered galvanoplastically with a thin even coat of copper, which was then amalgamated; finally, the contact was obtained by actually soldering the steel wires to pieces of heavy

[25] E. Obach: Hülfstafeln für Messungen elektrischer Leitungswiderstände mittelst der Kirchoff-Wheatstone'schen Drahtcombination, 1879.

copper wire. Only the last of these methods of insertion was found to be thoroughly satisfactory under all circumstances. In the first the error was quite large, while the second proved to be unsafe; for the amalgamated copper coat was apt to become insufficiently adhesive. In the case of glass-hard wire expeditious soldering is essential, otherwise the ends are annealed to an extent that will seriously affect the results. We avoided this at least partially by cooling the wire, immediately after the soldering had been effected, by a jet of water from a small wash-bottle. With a little practice the whole operation is finished in a few seconds. It is to be noted that if an error had been introduced in this way its effect would only have been that of giving further emphasis to the abnormally large results discussed in the sequel, since the values for specific resistance as thus actually found can only be short of the true values. In the later experiments all these inconveniences were avoided by the use of Hockin and Matthiessen's method.

*Criterion for homogeneity.*—The method just mentioned is peculiarly adapted for the determination of the degrees of uniformity of hardness along a given length of wire, because it enables the observer to compare the resistances of different parts of the said length with facility. The process as actually employed will be discussed in another chapter.

*The method used for calibrating* the essential wire of the bridge has been described elsewhere. (See appendix to this chapter, p. 72.)

## THE OPERATION OF SUDDEN COOLING. GLASS-HARDNESS.

*Effect of chemical composition.*—The steel rods tempered to glass-hardness in the manner described were found, on examination, to be thermo-electrically negative[26] relatively to silver.

In so far as the same process had been applied to rods nominally of like composition, it appeared plausibly presumable that the degrees of hardness attained would be nearly identical; in other words, that the tempering would have furnished us with a set of glass-hard rods of nearly the same thermo-electric power. This was not the case. A graphic representation of the relation between thermo-electromotive force and temperature showed this remarkable result, that the wires tempered were readily referable to a few distinct groups; for the position of the different thermo-electric curves was such as to permit them all to be comprehended by a few narrow and well-defined sectors. This implies that though the maximum of attainable hardness is different in the different wires, particular groups possessing nearly identical properties are readily discernible. We were unable to discover any relation between the individual members of the said groups and the

[26] Cf. preface, p. 6.

respective diameters of the wires. Nor did the wires hardened on any particular day show like thermo-electric qualities. It is conceivable, for instance, where currents of different intensity are employed, that the resulting difference in the degrees of red heat imparted to the wires would find its expression in a correspondingly marked difference in the degrees of hardness. The true cause of the difference of character observed must therefore be ascribed to chemical composition. In other words, the groups are distinguishable one from another by the respective amounts of carbon contained in the wires. The rods were not all received at the same time. Without doubt the maximum of hardness attainable by sudden chilling is essentially conditioned by the degree of carburation of the steel rod, and to a very small degree only by the impurities present. In a general way we may state that the maximum in question is a characteristic datum for the type of steel under experiment. In Chapter VII of the present memoir we shall have occasion to discuss this subject in detail.

*Maximum hardness reached.*—The greatest hardness met with in this work was that possessed by two rods of the diameters 0.056 cm. and 0.073 cm., respectively. The thermo-electric constant $a$ here reached the exceptionally small value $a = -2{\cdot}60$ (microvolts), and the specific resistance, at ordinary temperatures, was as large as 45 microhms, cm/cm$^3$. Unfortunately most of these very hard wires had to be discarded, because in the earlier experiments boiling water had been used in investigating their thermo-electric powers. We subsequently found that 100° produces a very pronounced annealing effect. In the later experiments with glass hard wires water of only 40° was employed, and this but for a very short period of time.

*Temperature of ignition.*—Jarolimek and Ackermann[27] in their experiments on steel arrived at the important result that the rapidity of the first part of the chilling of red-hot steel, say from 600° or 700° to 300° or 400°, is far more essential as regards the degree of hardness obtained than the further cooling from 300°–400° to zero. It is easily possible to harden a rod very perceptibly by cooling it from bright redness in a metallic bath (Zn, Pb) at 400°. Such a process combines in one the operations of chilling and of annealing. Cooling from 300° or 400°, however, produces no effect. Again, Chernoff had previously found that if the temperature from which steel is chilled be supposed to increase continuously, no observable effect will be apparent until a temperature in dark cherry-red heat is reached, when glass-hardness is suddenly attained.[28]

Our experience is in perfect accord with these results. The phenomenon was strikingly manifested both in rods of the same diameter and in

[27] Jarolimek u. Ackermann, Zeitschr. für das chem. Grossgewerbe, 1880. Similar results, we believe, were published by the distinguished American engineer, Mr. Joshua Rose, but we have been unable to find them.

[28] D. Chernoff: Vortrag gehalten in der russischen Technischen Gesellschaft, im April u. Mai 1868.

ness readily to a given comparatively thick class of wires, this was no longer possible for the next larger dimension, notwithstanding the fact that the respective thicknesses varied as little as 0.125 cm. and 0.145 cm. It is furthermore to be added that the sudden change in question is equally apparent both in the mechanical as well as in the electrical properties of steel.

The experiments made would certainly not warrant the forced assumption that the phenomenon in question partakes of the nature of a true discontinuity. Some molecular change occurring at an extremely rapid rate is alone to be understood. In a general way, however, it may be stated that a certain critical temperature in red heat must be surpassed if sudden cooling is to produce glass-hardness; otherwise the steel remains soft.

*Thermo-electric maxima and neutral points.*—In this place a final remark may be added. During the experiments we had frequent occasion to observe "neutral points" (occurring at the mean temperature $\frac{1}{2}(T+t)=\frac{1}{2}\frac{a}{b}$ of the junctions of the thermo-element, the temperature at which the electromotive force passes with a change of sign through zero of comparatively low value. Many of the hard rods differed but slightly from silver as regards their thermo-electric properties. Maxima of electromotive force at low temperatures were even more frequently obtained. A number of examples of this kind will be found in the tables below.

BEHAVIOR OF HARD STEEL RODS ANNEALED IN HOT OIL BATH

moving samples of the series of immersed rods at different stages of the process. Inequalities of temperature in the bath were reduced to a minimum by constant stirring. We also adopted an inverse method of procedure, in which, when a desired temperature was reached, the hard wires selected were submerged in the oil on a false bottom of wire gauze, and the whole allowed to cool. After several days they were examined both as to their thermo-electric power and their specific resistance.

*Results.*—The results of these measurements are given in the following table. It will be remembered that $e$ (observed or calculated as specified) is the electromotive force in microvolts for the temperature $T$ and $t$ (centigrade) of the junctions. $a$ and $b$ are the thermo-electric constants of Avenarius, $s$, $\left(\frac{\text{cm}}{\text{cm}^3}\text{t°microhm}\right)$ the specific resistance at the temperature $t$, $\rho$ (cm.) finally the radius of the wires:

TABLE 7.—*Thermo-electrics and conductivity of steel wires, annealed in oil baths.*

| Annealed at— | No. | $t$ | $T$ | $e:10^2$ observed. | $e:10^2$ calculated. | $a$ | $b$ | $s$ | $t$ |
|---|---|---|---|---|---|---|---|---|---|
| | | °C. | °C. | *microvolts.* | *microvolts.* | *microvolts.* | *microvolts.* | $\frac{\text{cm}}{\text{cm}^3}$ t *microhm.* | °C. |
| I. 200° .... | No. 1 (2$\rho$=0.0966) | 19.8 | 88.1 | 4.418 | 4.429 | 7.80 | —0.0127 | 18.96 | 19 |
| | | 19.3 | 74.0 | 3.622 | 3.615 | | | | |
| | | 19.8 | 63.3 | 2.982 | 2.971 | | | | |
| | | 19.8 | 50.1 | 2.125 | 2.131 | | | | |
| | No. 2 (2 $\rho$=0.0900) | 19.5 | 89.5 | 4.619 | 4.622 | 8.03 | —0.0130 | 18.49 | 19 |
| | | 19.5 | 76.2 | 3.849 | 3.843 | | | | |
| | | 19.5 | 62.0 | 2.961 | 2.959 | | | | |
| | | 19.5 | 54.3 | 2.457 | 2.458 | | | | |
| | No. 3 (2 $\rho$=0.0721) | 19.6 | 89.3 | 4.052 | 4.050 | 6.99 | —0.0111 | 20.54 | 19 |
| | | 19.7 | 78.3 | 3.194 | 3.191 | | | | |
| | | 19.6 | 59.1 | 2.406 | 2.414 | | | | |
| | | 19.7 | 50.1 | 1.896 | 1.886 | | | | |
| | No. 4 (2 $\rho$=0.0668) | 18.9 | 87.9 | 4.497 | 4.503 | 7.78 | —0.0118 | 20.00 | 19 |
| | | 18.9 | 70.3 | 3.468 | 3.462 | | | | |
| | | 18.9 | 57.4 | 2.657 | 2.651 | | | | |
| | | 18.9 | 48.3 | 2.052 | 2.056 | | | | |
| | No. 5 (2 $\rho$=0.0845) | 19.7 | 86.7 | 4.787 | 4.789 | 8.52 | —0.0130 | 17.64 | 19 |
| | | 19.7 | 72.1 | 3.847 | 3.843 | | | | |
| | | 19.7 | 59.4 | 2.975 | 2.977 | | | | |
| | | 19.7 | 50.6 | 2.353 | 2.352 | | | | |
| II. 275° ... | No. 6 (2 $\rho$=0.0903) | 20.0 | 89.2 | 3.987 | 3.985 | 7.24 | —0.0135 | 20.75 | 20 |
| | | 20.0 | 78.2 | 3.437 | 3.436 | | | | |
| | | 20.0 | 64.9 | 2.731 | 2.733 | | | | |
| | | 20.0 | 50.9 | 1.941 | 1.940 | | | | |
| | No. 7 (2 $\rho$=0.0656) | 20.0 | 90.1 | 3.553 | 3.562 | 6.15 | —0.0097 | 22.74 | 19 |
| | | 20.0 | 71.9 | 2.737 | 2.729 | | | | |
| | | 20.0 | 59.7 | 2.141 | 2.134 | | | | |
| | | 20.0 | 48.3 | 1.529 | 1.533 | | | | |
| III. 350° .. | No. 8 (2 $\rho$=0.0880) | 19.9 | 88.0 | 3.429 | 3.427 | 6.46 | —0.0132 | 23.20 | 19 |
| | | 19.9 | 74.8 | 2.863 | 2.860 | | | | |
| | | 19.9 | 61.6 | 2.237 | 2.244 | | | | |
| | | 19.9 | 51.9 | 1.767 | 1.763 | | | | |
| | No. 9 (2 $\rho$=0.0720) | 20.0 | 80.5 | 3.462 | 3.457 | 6.96 | —0.0124 | 20.47 | 19 |
| | | 20.0 | 65.8 | 2.697 | 2.701 | | | | |
| | | 20.0 | 55.3 | 2.124 | 2.128 | | | | |
| | | 20.0 | 49.9 | 1.827 | 1.822 | | | | |

TABLE 7.—*Thermo-electrics and conductivity of steel wires, annealed in oil baths*—Cont'd.

| Annealed at— | No. | $t$ | $T$ | $\epsilon : 10^6$ observed. | $\epsilon : 10^6$ calculated. | $a$ | $b$ | $\rho$ |
|---|---|---|---|---|---|---|---|---|
| | | °C. | °C. | *microvolts.* | *microvolts.* | *microvolts.* | *microvolts.* | $\frac{cm}{cm^2}$ microhm. |
| | No. 10 ($2\rho$=0.0720) | 20.0 | 79.9 | 2.161 | 2.159 | 4.67 | —0.0007 | 25.66 18 |
| | | 20.0 | 68.4 | 1.803 | 1.804 | | | |
| | | 20.0 | 57.3 | 1.335 | 1.340 | | | |
| | | 20.0 | 49.0 | 1.144 | 1.141 | | | |
| | No. 11 ($2\rho$=0.0565) | 20.1 | 87.1 | 2.663 | 2.672 | 5.15 | —0.0109 | 24.51 18 |
| | | 20.1 | 65.9 | 1.948 | 1.931 | | | |
| | | 20.1 | 53.9 | 1.464 | 1.469 | | | |
| | | 20.1 | 41.8 | 0.971 | 0.972 | | | |
| | No. 12 ($2\rho$=0.0548) | 20.1 | 89.4 | 3.442 | 3.434 | 6.40 | —0.0131 | 22.91 18 |
| | | 20.1 | 67.9 | 2.494 | 2.503 | | | |
| | | 20.1 | 55.3 | 1.900 | 1.902 | | | |
| | | 20.1 | 44.8 | 1.372 | 1.369 | | | |
| | No. 13 ($2\rho$=0.0337) | 20.1 | 87.4 | 3.770 | 3.769 | 6.89 | —0.0121 | 23.66 18 |
| | | 20.1 | 74.0 | 3.105 | 3.107 | | | |
| | | 20.1 | 62.4 | 2.498 | 2.496 | | | |
| | | 20.1 | 52.0 | 1.922 | 1.923 | | | |
| IV. 225°... | No. 14 ($2\rho$=0.0900) | 19.9 | 89.2 | 2.059 | 2.068 | 4.06 | —0.0086 | 27.36 18 |
| | | 19.9 | 75.6 | 1.751 | 1.757 | | | |
| | | 19.9 | 64.4 | 1.434 | 1.437 | | | |
| | | 19.9 | 54.9 | 1.161 | 1.163 | | | |
| | No. 15 ($2\rho$=0.0558) | 20.1 | 89.5 | 1.989 | 1.989 | 3.85 | —0.0090 | 28.11 18 |
| | | 20.1 | 68.8 | 1.484 | 1.489 | | | |
| | | 20.1 | 69.1 | 1.231 | 1.225 | | | |
| | | 20.1 | 50.1 | 0.963 | 0.965 | | | |
| V. 200°.... | No. 16 ($2\rho$=0.0974) | 18.9 | 89.8 | 2.524 | 2.528 | 4.67 | —0.0103 | 26.70 18 |
| | | 18.9 | 74.3 | 2.063 | 2.063 | | | |
| | | 18.9 | 61.1 | 1.631 | 1.626 | | | |
| | | 18.9 | 51.7 | 1.294 | 1.297 | | | |
| | No. 17 ($2\rho$=0.0882) | 18.9 | 82.5 | 2.056 | 2.056 | 4.26 | —0.0102 | 27.93 18 |
| | | 19.0 | 68.8 | 1.681 | 1.678 | | | |
| | | 18.9 | 59.8 | 1.414 | 1.417 | | | |
| | | 19.0 | 51.9 | 1.166 | 1.165 | | | |
| | No. 18 ($2\rho$=0.0723) | 19.1 | 78.8 | 1.314 | 1.312 | 2.79 | —0.0060 | 31.22 18 |
| | | 19.1 | 68.2 | 1.109 | 1.112 | | | |
| | | 19.1 | 57.8 | 0.899 | 0.900 | | | |
| | | 19.1 | 48.7 | 0.706 | 0.705 | | | |
| | No. 19 ($2\rho$=0.0560) | 18.1 | 82.0 | 1.859 | 1.862 | 3.83 | —0.0091 | 28.68 18 |
| | | 18.1 | 62.8 | 1.387 | 1.381 | | | |
| | | 18.1 | 47.8 | 0.954 | 0.958 | | | |
| | | 18.2 | 39.8 | 0.714 | 0.713 | | | |
| | No. 20 ($2\rho$=0.0336) | 18.3 | 76.8 | 2.723 | 2.715 | 5.45 | —0.0086 | 24.34 18 |
| | | 18.3 | 62.3 | 2.088 | 2.098 | | | |
| | | 18.3 | 52.9 | 1.680 | 1.677 | | | |
| | | 18.3 | 42.1 | 1.177 | 1.176 | | | |
| VI. 175°... | No. 21 ($2\rho$=0.0908) | 18.8 | 86.4 | 1.828 | 1.809 | 3.76 | —0.0103 | 29.34 18 |
| | | 18.8 | 67.1 | 1.366 | 1.388 | | | |
| | | 18.8 | 53.8 | 1.061 | 1.054 | | | |
| | | 18.8 | 43.3 | 0.765 | 0.763 | | | |
| | No. 22 ($2\rho$=0.0571) | 18.8 | 87.2 | 1.734 | 1.729 | 3.41 | —0.0083 | 30.94 18 |
| | | 18.9 | 72.4 | 1.414 | 1.417 | | | |
| | | 18.8 | 59.7 | 1.122 | 1.126 | | | |
| | | 18.9 | 48.8 | 0.854 | 0.850 | | | |
| VII. 150°. | No. 23 ($2\rho$=0.0385) | 18.5 | 78.7 | 1.745 | 1.744 | 4.24 | —0.0117 | 27.93 18 |
| | | 18.5 | 60.4 | 1.387 | 1.390 | | | |
| | | 18.5 | 52.1 | 1.146 | 1.147 | | | |
| | | 18.5 | 45.4 | 0.941 | 0.939 | | | |

*Digest.*—If we arrange these different degrees of hardness, expressed both thermo-electrically and in terms of their specific resistance, with reference to continuous variation of the former quantity, we obtain

the following perspicuous tabular comparison. The table shows that our endeavor to reach a great number of symmetrically distributed degrees of hardness systematically, was only partially successful.

TABLE 8.—*Thermo-electric position and conductivity of annealed steel.*

| No. | $a$ | $s$ | Annealed at | No. | $a$ | $s$ | Annealed at |
|---|---|---|---|---|---|---|---|
| | *microvolts.* | *microhms.* | °C. | | *microvolts.* | *microhms.* | °C. |
| 5 | 8.52 | 17.64 | 300 | 11 | 5.15 | 24.81 | 250 |
| 2 | 8.03 | 18.49 | 300 | 16 | 4.67 | 26.70 | 200 |
| 1 | 7.80 | 18.96 | 300 | 10 | 4.67 | 25.66 | 250 |
| 4 | 7.78 | 20.00 | 300 | 17 | 4.26 | 27.93 | 200 |
| 6 | 7.24 | 20.75 | 275 | 23 | 4.24 | 27.93 | 150 |
| 3 | 6.99 | 20.54 | 300 | 14 | 4.06 | 27.36 | 225 |
| 9 | 6.96 | 20.47 | 250 | 15 | 3.85 | 28.11 | 225 |
| 13 | 6.89 | 20.66 | 250 | 19 | 3.83 | 28.68 | 200 |
| 8 | 6.46 | 23.20 | 250 | 21 | 3.76 | 29.34 | 175 |
| 12 | 6.40 | 22.93 | 250 | 22 | 3.41 | 30.94 | 175 |
| 7 | 6.15 | 22.74 | 275 | 18 | 2.79 | 31.32 | 200 |
| 20 | 5.45 | 24.84 | 200 | | | | |

## ON THE BEARING OF THE TIME OF EXPOSURE ON THE EFFICACY OF ANNEALING.

*Low annealing temperatures.*—In the foregoing experiments the lowest temperature employed was 150°. It will be seen that the annealing effect thus produced is strikingly large. This observation naturally suggested the question as to what results are to be expected when the annealing is conducted even at lower temperatures. The inquiry would have an immediate practical bearing: It will be remembered that in the thermo-electric measurements it is desirable to raise one of the junctions to a high temperature relatively to the other. We are led to ask, therefore, how high this temperature may be chosen without destroying uniformity of temper and producing partial annealing at one end of the rod.

*Results for* 100°.—We began the preliminary experiments with the two rods, Nos. 24 and 25, of nearly the same thicknesses, 0.0574 cm. and 0.0554 cm., respectively, but of different degrees of glass-hardness. Thermo-electric measurements only were made, with results for the glass-hard state as follows:

TABLE 9.—*Thermo-electric power of glass-hard wires.*

| | $t$ | $T$ | $e:10^2$ observed. | $e:10^2$ calculated. | $a$ | $b$ |
|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* |
| No. 24 | 12.5 | 88.1 | −2.809 | −2.793 | −2.83 | −0.0096 |
| | 12.5 | 78.8 | −2.376 | −2.396 | | |
| | 12.5 | 58.1 | −1.572 | −1.567 | | |
| | 12.6 | 44.1 | −1.139 | −1.139 | | |
| No. 25 | 12.3 | 89.0 | −0.707 | −0.697 | +0.13 | −0.0108 |
| | 12.4 | 80.1 | −0.552 | −0.554 | | |
| | 12.4 | 71.2 | −0.415 | −0.428 | | |
| | 12.4 | 59.8 | −0.294 | −0.289 | | |

These wires were now exposed to the action of steam at 100° for a period of one hour, in an ordinary boiling-point apparatus. The measurement of thermo-electric position made on the following day showed these values:

TABLE 10.—*Hard wires, 1h at 100°.*

| | $t$ | $T$ | $e:10^2$ observed. | $e:10^2$ calculated. | $a$ | $b$ |
|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* |
| No. 24[1] | 16.9 | 59.4 | −0.069 | −0.069 | +0.61 | −0.0102 |
| | 16.9 | 50.7 | −0.025 | −0.025 | | |
| | 16.9 | 45.2 | −0.005 | −0.005 | | |
| | 16.9 | 39.9 | +0.008 | +0.008 | | |
| No. 25 | 16.9 | 76.1 | 1.030 | 1.029 | +2.75 | −0.0189 |
| | 16.9 | 65.2 | 0.893 | 0.890 | | |
| | 16.9 | 54.7 | 0.750 | 0.746 | | |
| | 16.9 | 46.0 | 0.599 | 0.600 | | |

[1] Neutral point: $(T+t)=-\frac{a}{b}=60°.2$; $\therefore T=43°.3$.

From a comparison of the values of $a$ before and after annealing at 100°, a variation of thermo-electric power, therefore also of mechanical state, is very strikingly apparent; whence it follows at once that in the measurements of $e$, the use of boiling water in the hot receiver in the case of very hard wires is under no circumstances permissible. Indeed, from the magnitude of the variation in question, we infer that temperatures even much lower than 100° will show a tendency to produce an annealing effect seriously detrimental to a uniformity of the temper of the wire.

The above experiment was repeated. The rods were again annealed at 100° for a period of one hour, and thermo-electrically examined on the following day.

TABLE 11.—*Hard wires, 2h at 100°.*

| | $t$ | $T$ | $e:10^2$ observed. | $e:10^2$ calculated. | $a$ | $b$ |
|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* |
| No. 24[2] | 17.4 | 73.8 | 0.142 | 0.152 | 1.26 | −0.0110 |
| | 17.4 | 64.7 | 0.184 | 0.174 | | |
| | 17.4 | 56.1 | 0.163 | 0.178 | | |
| | 17.3 | 49.3 | 0.162 | 0.167 | | |
| No. 25 | 17.3 | 71.1 | 1.256 | 1.249 | 3.64 | −0.0150 |
| | 17.3 | 61.6 | 1.093 | 1.092 | | |
| | 17.4 | 53.4 | 0.916 | 0.932 | | |
| | 17.4 | 46.7 | 0.794 | 0.787 | | |

[2] Maximum at $T=-\frac{1}{2}\frac{a}{b}=57°.8$; observed, $y=18.5$; calc., $y=17.8$.

The results again show a smaller but nevertheless clearly pronounced variation of thermo-electric power, and we arrive at the important conclusion that, in addition to the temperature of the annealing bath, a second factor is essential in conditioning the resultant hardness, namely, the interval of *time* during which the annealing is prolonged, or the rod exposed to the given temperature.

With the object of discovering the nature of this time-effect, the experiments were continued in the same way. The results are contained in the following tables:

TABLE 12.—*Hard wires 3h at 100°.*

| | $t$ | $T$ | $\epsilon : 10^2$ observed. | $\epsilon : 10^2$ calculated. | $a$ | $b$ |
|---|---|---|---|---|---|---|
| | °C. | °C. | microvolt. | microvolt. | microvolt. | microvolt. |
| No. 24 | 17.5 | 74.1 | 0.329 | 0.327 | 0.161 | −0.0111 |
| | 17.5 | 62.0 | 0.316 | 0.318 | | |
| | 17.5 | 54.2 | 0.294 | 0.294 | | |
| | 17.5 | 48.6 | 0.270 | 0.269 | | |
| No. 25 | 17.5 | 74.3 | 1.499 | 1.497 | 3.55 | −0.0100 |
| | 17.5 | 62.7 | 1.242 | 1.245 | | |
| | 17.5 | 53.8 | 1.033 | 1.033 | | |
| | 17.5 | 49.2 | 0.926 | 0.926 | | |

TABLE 13.—*Hard wires 4h at 100°.*

| | $t$ | $T$ | $\epsilon : 10^2$ observed. | $\epsilon : 10^2$ calculated. | $a$ | $b$ |
|---|---|---|---|---|---|---|
| | °C. | °C. | microvolt. | microvolt. | microvolt. | microvolt. |
| No. 24 | 17.7 | 86.4 | 0.484 | 0.487 | 1.76 | −0.0101 |
| | 17.7 | 77.5 | 0.480 | 0.477 | | |
| | 17.7 | 66.4 | 0.444 | 0.445 | | |
| | 17.7 | 54.7 | 0.379 | 0.379 | | |
| No. 25 | 17.7 | 87.4 | 1.886 | 1.887 | 3.77 | −0.0102 |
| | 17.7 | 76.1 | 1.660 | 1.648 | | |
| | 17.7 | 67.7 | 1.447 | 1.453 | | |
| | 17.7 | 56.5 | 1.177 | 1.182 | | |

TABLE 14.—*Hard wires 5h at 100°.*

| | $t$ | $T$ | $\epsilon : 10^2$ observed. | $\epsilon : 10^2$ calculated. | $a$ | $b$ |
|---|---|---|---|---|---|---|
| | °C. | °C. | microvolt. | microvolt. | microvolt. | microvolt. |
| No. 24 | 17.0 | 71.6 | 0.500 | 0.502 | 1.70 | −0.0075 |
| | 17.0 | 58.4 | 0.477 | 0.468 | | |
| | 17.0 | 44.5 | 0.326 | 0.340 | | |
| | 17.0 | 34.5 | 0.233 | 0.228 | | |
| No. 25 | 17.1 | 75.0 | 1.661 | 1.665 | 3.90 | −0.0111 |
| | 17.1 | 62.1 | 1.363 | 1.358 | | |
| | 17.1 | 53.6 | 1.136 | 1.138 | | |
| | 17.1 | 47.0 | 0.952 | 0.954 | | |

TABLE 15.—*Hard wires 6h at 100°.*

| | $t$ | $T$ | $\epsilon : 10^2$ observed. | $\epsilon : 10^2$ calculated. | $a$ | $b$ |
|---|---|---|---|---|---|---|
| | °C. | °C. | microvolt. | microvolt. | microvolt. | microvolt. |
| No. 24 | 17.5 | 82.6 | 0.637 | 0.641 | 1.92 | −0.0093 |
| | 17.5 | 57.1 | 0.483 | 0.483 | | |
| | 17.5 | 40.7 | 0.319 | 0.329 | | |
| | 17.5 | 33.9 | 0.230 | 0.236 | | |
| No. 25 | 17.4 | 72.0 | 1.628 | 1.632 | 4.02 | −0.0115 |
| | 17.4 | 48.7 | 1.018 | 1.019 | | |
| | 17.4 | 36.3 | 0.648 | 0.642 | | |
| | 17.4 | 27.5 | 0.351 | 0.355 | | |

*Digest.*—The relation between $a$ and the time of exposure is more perspicuously apparent in the following comparison:

| | 0h | 1h | 2h | 3h | 4h | 5h | 6h |
|---|---|---|---|---|---|---|---|
| (24) ..... $a$= | −2.83 | +0.61 | 1.26 | 1.61 | 1.76 | 1.70 | 1.92 |
| (25) ..... $a$= | +0.13 | 2.75 | 3.64 | 3.55 | 3.77 | 3.90 | 4.02 |

From this grouping of parallel results, or, more evidently still, from a graphic representation (time as abscissa, thermo-electric constant as ordinate, mean values of Nos. 24 and 25, figure 9), it will be seen that

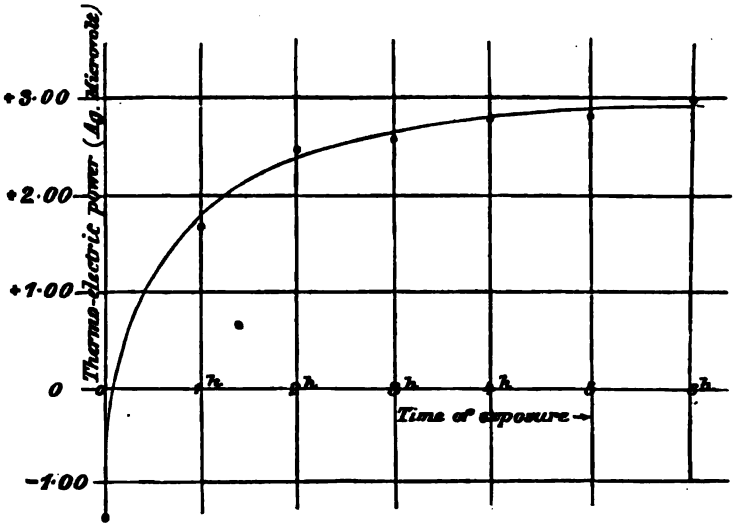



FIG. 9.—Hard wires annealed for six consecutive hours in steam at 100°.

hardness varies continuously with the time of exposure of the glass-hard rod to the given annealing temperature; that the amount of thermo-electric change rapidly decreases as the time increases, until finally a definite and superior limiting value is asymptotically reached.[29]

After these introductory experiments we determined to investigate

[29]Among the above results the individual values of $a$, 1.70 for the first and 3.77 for the second rod, require comment. It is obvious that from the four observations for each, probably affected with larger errors than usual, the method of least squares has not derived the constants in closest accordance with fact. This betrays itself in the values obtained for $b$, which differ largely from the average values. The constant $b$ varies but slightly (as a general mean $-b=0.0100$ may be accepted). Associated with the values of $a$ in question, however, we have $-b=0.0075$ (corresponding to the small result $a=1.70$) and $-b=0.0102$ (corresponding to the large result $a=3.77$). But in view of the fact that the function of which $a$ is the coefficient is positive, and that in which $b$ is involved, negative, the errors of both $a$ and $b$ are partially eliminated in the sum, so that observed $e$ and calculated $e$ are again in satisfactory accordance.

the phenomena of annealing more rigidly, giving the effect of time of exposure due prominence. Besides the boiling point of water, that of methyl alcohol at 66°.0 and that of aniline at 185° were chosen for annealing, the wires being suspended in vapors of these substances circulating in a glass boiling-point apparatus. A still higher temperature (330°) was furnished by the melting point of lead. Batches of three wires of different diameters and different degrees of glass-hardness were selected to be annealed respectively at each of these temperatures. To trace the effects resulting, simultaneous determinations, both of thermo-electric power and conductivity, were made at as many stages of the process as appeared desirable. The data are contained in the tables 16–28.

## BEHAVIOR OF HARD STEEL ANNEALED IN VAPOR OF BOILING METHYL ALCOHOL (66°).

The rods selected were:

No. 28; diameter $(2\rho)=0.0827$ cm.,
No. 29; diameter $(2\rho)=0.0631$ cm.,
No. 30; diameter $(2\rho)=0.0479$ cm.

After the thermo-electric power (microvolts) and specific resistance (microhms) for the glass-hard state had been determined, the wires were subjected to the annealing influence of vapor of methyl alcohol at 66° for three consecutive hours, and at the end of each hour examined by the aid of the electrical qualities in question. The results are these:

TABLE 16.—*Hard steel annealed at* 66°.

[Rod No. 28. $2\rho=0.0827$.]

| Remarks. | $t$ | $T$ | $e:10^2$ observed. | $e:10^2$ calculated. | $a$ | $b$ | $s_t^0$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | microvolt. | microvolt. | microvolt. | microvolt. | $\frac{cm}{cm^3}$ to microhm. | °C. |
| Glass-hard | 18.7 | 54.8 | −1.003 | −0.999 | | | | |
| | 18.7 | 48.9 | −0.907 | −0.904 | −2.56 | −0.0064 | 42.64 | 18 |
| | 18.7 | 43.4 | −0.721 | −0.731 | | | | |
| | 18.7 | 35.6 | −0.495 | −0.492 | | | | |
| 1h in vapor of methyl alcohol, t=66°.0. | 18.1 | 58.2 | −1.033 | −1.027 | | | | |
| | 18.1 | 52.4 | −0.962 | −0.937 | −1.94 | −0.0111 | 42.55 | 18 |
| | 18.1 | 47.9 | −0.792 | −0.798 | | | | |
| | 18.1 | 42.0 | −0.629 | −0.626 | | | | |
| 1h more in vapor of methyl alcohol, t=66°.0. | 18.3 | 58.5 | −0.968 | −0.964 | | | | |
| | 18.4 | 49.4 | −0.785 | −0.787 | −1.81 | −0.0107 | 42.45 | 19 |
| | 18.3 | 42.9 | −0.601 | −0.608 | | | | |
| | 18.4 | 38.7 | −0.497 | −0.492 | | | | |
| 1h more in vapor of methyl alcohol, t=66°.0. | 20.0 | 60.6 | −0.956 | −0.947 | | | | |
| | 20.0 | 51.5 | −0.767 | −0.774 | −1.58 | −0.0122 | 42.55 | 19 |
| | 20.0 | 46.4 | −0.625 | −0.632 | | | | |
| | 20.0 | 39.4 | −0.453 | −0.448 | | | | |

TABLE 17.—*Hard steel annealed at 66°.*

[Rod No. 29. $2\rho=0.0631$.]

| Remarks. | $t$ | $T$ | $\epsilon : 10^2$ observed. | $\epsilon : 10^2$ calculated. | $a$ | $b$ | $\kappa$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^2 °}$ microhm. | °C. |
| Glass-hard | 18.7 | 50.4 | −0.606 | −0.607 | | | | |
| | 18.8 | 44.5 | −0.564 | −0.559 | | | | |
| | 18.7 | 38.8 | −0.429 | −0.432 | −1.90 | −0.0044 | 42.66 | 17 |
| | 18.8 | 34.8 | −0.343 | −0.342 | | | | |
| 1% in vapor of methyl alcohol, t=66°.0. | 18.2 | 57.7 | −0.704 | −0.702 | | | | |
| | 18.2 | 51.7 | −0.579 | −0.581 | | | | |
| | 18.2 | 45.8 | −0.467 | −0.467 | −1.25 | −0.0076 | 41.79 | 18 |
| | 18.2 | 40.4 | −0.378 | −0.378 | | | | |
| 1% more in vapor of methyl alcohol, t=66°.0. | 18.5 | 57.2 | −0.636 | −0.639 | | | | |
| | 18.5 | 49.4 | −0.487 | −0.486 | | | | |
| | 18.5 | 43.9 | −0.385 | −0.387 | −0.91 | −0.0098 | 41.52 | 19 |
| | 18.5 | 40.1 | −0.324 | −0.321 | | | | |
| 1% more in vapor of methyl alcohol, t=66°.0. | 19.9 | 61.4 | −0.624 | −0.620 | | | | |
| | 19.9 | 53.2 | −0.469 | −0.471 | | | | |
| | 19.9 | 45.8 | −0.334 | −0.340 | −0.70 | −0.0088 | 41.42 | 19 |
| | 19.9 | 41.1 | −0.280 | −0.275 | | | | |

TABLE 18.—*Hard steel annealed at 66°.*

[Rod No. 30. $2\rho=0.0479$.]

| Remarks. | $t$ | $T$ | $\epsilon : 10^2$ observed. | $\epsilon : 10^2$ calculated. | $a$ | $b$ | $\kappa$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^2 °}$ microhm. | °C. |
| Glass-hard | 18.7 | 54.2 | −0.335 | −0.329 | | | | |
| | 18.7 | 45.3 | −0.223 | −0.229 | | | | |
| | 18.7 | 40.2 | −0.175 | −0.178 | −0.42 | −0.0071 | 37.66 | 18 |
| | 18.7 | 34.4 | −0.126 | −0.124 | | | | |
| 1% in vapor of methyl alcohol, t=66°.0. | 17.8 | 56.9 | −0.209 | −0.209 | −0.01 | −0.0079 | 36.89 | 18 |
| | 20.1 | 45.1 | −0.117 | −0.117 | | | | |
| 1% more in vapor of methyl alcohol, t=66°.0. | 19.2 | 59.1 | −0.105 | −0.103 | | | | |
| | 19.2 | 54.5 | −0.079 | −0.079 | | | | |
| | 19.2 | 49.0 | −0.054 | −0.055 | +0.30 | −0.0074 | 36.51 | 18 |
| | 19.2 | 42.6 | −0.031 | −0.032 | | | | |
| | 19.2 | 38.4 | −0.023 | −0.021 | | | | |
| 1% more in vapor of methyl alcohol, t=66°.0.[1] | 19.8 | 54.6 | −0.003 | −0.002 | | | | |
| | 19.9 | 49.7 | +0.009 | +0.008 | | | | |
| | 19.8 | 45.0 | 0.015 | 0.014 | +0.47 | −0.0065 | 36.42 | 19 |
| | 19.9 | 38.2 | 0.018 | 0.018 | | | | |

[1] Neutral point: $(T+t)=-\frac{a}{b}=72.5$; $\therefore T=53°.7$.

## BEHAVIOR OF HARD STEEL ANNEALED IN STEAM (100°).

The rods selected were:

No. 31; diameter $(2\rho)=0.0833$ cm.,
No. 32; diameter $(2\rho)=0.0616$ cm.,
No. 33; diameter $(2\rho)=0.0491$ cm.

Our earlier experiments with rods Nos. 24 and 25 had shown that the effect of annealing in steam is particularly marked during the first hour of exposure. We therefore decided to obtain intermediate stages by making interruptions and examinations after each of the first 10, 30, and 60 minutes of this interval. After this the rods were annealed during two hours more, as above. The results for the hardness in the original (glass-hard) and subsequent states are fully given in the following tables:

TABLE 19.—*Hard steel annealed at* 100°.

[Rod No. 31. $2\rho=0.0839$.]

| Remarks. | $t$ | $T$ | $\epsilon:10^2$ observed. | $\epsilon:10^2$ calculated. | $a$ | $b$ | $s_t$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^2}_t$ *microhm.* | °C. |
| Glass-hard..... ..... | 22.5 | 55.2 | −0.621 | −0.624 | | | | |
| | 22.5 | 51.3 | −0.542 | −0.539 | −1.20 | −0.0093 | 40.47 | 21 |
| | 22.4 | 44.9 | −0.410 | −0.409 | | | | |
| | 22.4 | 39.6 | −0.303 | −0.304 | | | | |
| 10m in steam at 100°..... | 19.7 | 61.0 | −0.335 | −0.332 | | | | |
| | 19.7 | 55.4 | −0.296 | −0.299 | −0.08 | −0.0090 | 39.05 | 20 |
| | 19.7 | 48.7 | −0.202 | −0.202 | | | | |
| | 19.7 | 42.9 | −0.150 | −0.150 | | | | |
| 20m more in steam at 100°. | 18.5 | 76.0 | −0.177 | −0.170 | | | | |
| | 18.5 | 65.7 | −0.094 | −0.095 | +0.55 | −0.0090 | 37.64 | 19 |
| | 18.5 | 49.4 | −0.009 | −0.018 | | | | |
| | 18.5 | 37.5 | +0.006 | +0.009 | | | | |
| 30m more in steam at 100°. | 18.1 | 63.5 | +0.122 | +0.124 | | | | |
| | 18.1 | 56.9 | 0.126 | 0.125 | 0.86 | −0.0072 | 36.33 | 19 |
| | 18.1 | 50.0 | 0.118 | 0.118 | | | | |
| | 18.1 | 44.5 | 0.107 | 0.107 | | | | |
| 1h more in steam at 100°.. | 18.2 | 72.4 | 0.330 | 0.329 | | | | |
| | 18.2 | 58.8 | 0.304 | 0.304 | 1.55 | −0.0104 | 35.38 | 18 |
| | 18.3 | 51.0 | 0.270 | 0.271 | | | | |
| | 18.3 | 45.4 | 0.242 | 0.241 | | | | |
| 1h more in steam at 100°.. | 19.2 | 71.4 | 0.457 | 0.455 | | | | |
| | 19.3 | 61.4 | 0.410 | 0.410 | 1.81 | −0.0103 | 34.72 | 18 |
| | 19.2 | 55.2 | 0.371 | 0.374 | | | | |
| | 19.3 | 47.2 | 0.314 | 0.312 | | | | |

TABLE 20.—*Hard steel annealed at* 100°.

[Rod No. 32. $2\rho = 0.0616$.]

| Remarks. | $t$ | $T$ | $e$: $10^2$ observed. | $e$: $10^2$ calculated. | $a$ | $b$ | $s_t$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^2}_t$ *microhm.* | °C. |
| Glass-hard | 20.7 | 50.7 | −0.659 | −0.659 | −1.44 | −0.0106 | 41.42 | 21 |
| | 20.7 | 46.0 | −0.545 | −0.544 | | | | |
| | 20.7 | 41.9 | −0.437 | −0.448 | | | | |
| 10m in steam at 100° | 19.2 | 56.7 | −0.269 | −0.266 | −0.39 | −0.0042 | 39.53 | 20 |
| | 19.3 | 53.4 | −0.235 | −0.238 | | | | |
| | 19.2 | 44.7 | −0.168 | −0.168 | | | | |
| | 19.3 | 40.4 | −0.137 | −0.136 | | | | |
| 20m more in steam at 100°[1] | 18.5 | 70.1 | 0.075 | 0.075 | 0.80 | −0.0075 | 36.02 | 19 |
| | 18.5 | 63.6 | 0.090 | 0.088 | | | | |
| | 18.6 | 56.0 | 0.094 | 0.094 | | | | |
| | 18.6 | 44.8 | 0.088 | 0.088 | | | | |
| 30m more in steam at 100° | 18.0 | 59.1 | 0.291 | 0.294 | 1.39 | −0.0086 | 34.33 | 19 |
| | 18.0 | 49.6 | 0.260 | 0.253 | | | | |
| | 18.0 | 44.7 | 0.225 | 0.225 | | | | |
| | 18.0 | 41.4 | 0.201 | 0.203 | | | | |
| 1h more in steam at 100° | 17.7 | 55.7 | 0.519 | 0.519 | 2.01 | −0.0089 | 35.19 | 18 |
| | 17.7 | 49.5 | 0.451 | 0.451 | | | | |
| | 17.7 | 41.8 | 0.357 | 0.359 | | | | |
| | 17.7 | 36.4 | 0.288 | 0.287 | | | | |
| 1h more in steam at 100° | 19.2 | 67.3 | 0.754 | 0.754 | 2.26 | −0.0080 | 34.34 | 18 |
| | 19.3 | 58.9 | 0.650 | 0.648 | | | | |
| | 19.2 | 52.0 | 0.556 | 0.556 | | | | |
| | 19.2 | 45.8 | 0.463 | 0.463 | | | | |

[1] Maximum at $T = -\frac{1}{2}\frac{a}{b} = 53°.1$.

TABLE 21.—*Hard steel annealed at* 100°.

[Rod No. 33. $2\rho = 0.0491$.]

| Remarks. | $t$ | $T$ | $e$: $10^2$ observed. | $e$: $10^2$ calculated. | $a$ | $b$ | $s_t$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^2}_t$ *microhm.* | °C. |
| Glass-hard | 20.5 | 57.0 | −0.379 | −0.381 | −0.97 | −0.0122 | 36.98 | 21 |
| | 20.6 | 52.3 | −0.307 | −0.306 | | | | |
| | 20.6 | 45.9 | −0.226 | −0.224 | | | | |
| | 20.6 | 41.2 | −0.170 | −0.171 | | | | |
| 10m in steam at 100° | 19.2 | 58.6 | 0.151 | 0.150 | 0.97 | −0.0076 | 35.00 | 20 |
| | 19.2 | 51.7 | 0.142 | 0.142 | | | | |
| | 19.2 | 44.4 | 0.124 | 0.124 | | | | |
| | 19.2 | 37.8 | 0.100 | 0.100 | | | | |
| 20m more in steam at 100° | 18.4 | 53.2 | 0.361 | 0.364 | 1.50 | −0.0062 | 33.58 | 19 |
| | 18.4 | 44.7 | 0.294 | 0.290 | | | | |
| | 18.4 | 37.5 | 0.221 | 0.218 | | | | |
| | 18.4 | 32.5 | 0.163 | 0.166 | | | | |
| 30m more in steam at 100° | 18.0 | 56.3 | 0.632 | 0.634 | 2.25 | −0.0079 | 32.26 | 19 |
| | 18.1 | 47.8 | 0.517 | 0.510 | | | | |
| | 18.0 | 41.9 | 0.418 | 0.423 | | | | |
| | 18.1 | 32.0 | 0.256 | 0.257 | | | | |
| 1h more in steam at 100° | 18.0 | 66.1 | 0.881 | 0.893 | 2.67 | −0.0097 | 31.23 | 18 |
| | 18.0 | 58.6 | 0.795 | 0.783 | | | | |
| | 18.0 | 51.4 | 0.670 | 0.668 | | | | |
| | 18.0 | 42.1 | 0.500 | 0.504 | | | | |
| 1h more in steam at 100° | 19.3 | 67.3 | 1.071 | 1.070 | 3.00 | −0.0090 | 30.67 | 18 |
| | 19.3 | 58.1 | 0.895 | 0.897 | | | | |
| | 19.3 | 50.2 | 0.737 | 0.737 | | | | |
| | 19.3 | 40.8 | 0.521 | 0.521 | | | | |

## BEHAVIOR OF HARD STEEL ANNEALED IN VAPOR OF BOILING ANILINE (185°).

The details of the operations in this case were the same as those described in the foregoing paragraph. The rods used were:

No. 34; diameter $(2\rho)=0.0835$ cm.,
No. 35: diameter $(2\rho)=0.0627$ cm.,
No. 36; diameter $(2\rho)=0.0481$ cm.

The results obtained are the following:

TABLE 22.—*Hard steel annealed at* 185°.

[Rod No. 34. $2\rho=0.0835$.]

| Remarks. | $t$ | $T$ | $\epsilon : 10^2$ observed. | $\epsilon : 10^2$ calculated. | $a$ | $b$ | $a_1$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{c\,m^{st}}$ *microhm.* | °C. |
| Glass-hard..... | 22.1 | 59.2 | −0.573 | −0.569 | | | | |
| | 22.1 | 51.1 | −0.422 | −0.425 | −0.83 | −0.0087 | 39.34 | 21 |
| | 22.1 | 44.2 | −0.313 | −0.313 | | | | |
| | 22.0 | 39.5 | −0.239 | −0.238 | | | | |
| $10^m$ in vapor of aniline at 185°. | 19.5 | 71.0 | 1.414 | 1.423 | | | | |
| | 19.5 | 62.8 | 1.235 | 1.228 | 3.59 | −0.0090 | 29.25 | 20 |
| | 19.5 | 52.8 | 0.981 | 0.975 | | | | |
| | 19.5 | 43.6 | 0.722 | 0.726 | | | | |
| $30^m$ more in vapor of aniline at 185°. | 18.7 | 77.5 | 2.694 | 2.700 | | | | |
| | 18.7 | 59.8 | 1.321 | 1.312 | 4.10 | −0.0116 | 28.02 | 19 |
| | 18.7 | 49.7 | 1.025 | 1.027 | | | | |
| | 18.7 | 42.9 | 0.817 | 0.820 | | | | |
| $30^m$ more in vapor of aniline at 185°. | 18.2 | 71.0 | 1.717 | 1.721 | | | | |
| | 18.2 | 65.1 | 1.568 | 1.562 | 4.33 | −0.0121 | 27.17 | 19 |
| | 18.2 | 56.9 | 1.325 | 1.327 | | | | |
| | 18.2 | 45.9 | 0.986 | 0.986 | | | | |
| $1^h$ more in vapor of aniline at 185°. | 18.2 | 76.9 | 2.054 | 2.052 | | | | |
| | 18.2 | 68.2 | 1.895 | 1.899 | 4.61 | −0.0118 | 26.32 | 18 |
| | 18.2 | 61.1 | 1.579 | 1.581 | | | | |
| | 18.2 | 52.5 | 1.298 | 1.297 | | | | |
| $1^h$ more in vapor of aniline at 185°. | 19.3 | 88.5 | 2.453 | 2.454 | | | | |
| | 19.3 | 74.3 | 2.043 | 2.045 | 4.84 | −0.0121 | 25.85 | 18 |
| | 19.3 | 65.9 | 1.782 | 1.779 | | | | |
| | 19.3 | 58.4 | 1.526 | 1.528 | | | | |

TABLE 23.—*Hard steel annealed at* 185°.

[Rod No. 35. $2\rho$=0.0627.]

| Remarks. | $t$ | $T$ | $e:10^3$ observed. | $e:10^3$ calculated. | $a$ | $b$ | $\alpha$ |
|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^2}$ °C. microvolt. |
| Glass-hard | 22.1 | 56.5 | −0.847 | −0.846 | −1.97 | −0.0059 | 42.6 |
| | 22.2 | 50.4 | −0.680 | −0.684 | | | |
| | 22.1 | 44.4 | −0.538 | −0.534 | | | |
| | 22.1 | 39.1 | −0.402 | −0.402 | | | |
| 10m in vapor of aniline at 185°. | 19.8 | 65.0 | 1.531 | 1.532 | 4.22 | −0.0097 | 21.8 |
| | 19.9 | 57.0 | 1.292 | 1.297 | | | |
| | 19.9 | 49.2 | 1.032 | 1.038 | | | |
| | 19.9 | 42.6 | 0.821 | 0.819 | | | |
| 20m more in vapor of aniline at 185°. | 18.5 | 75.6 | 2.078 | 2.081 | 4.75 | −0.0118 | 27.3 |
| | 18.5 | 66.6 | 1.812 | 1.808 | | | |
| | 18.6 | 56.2 | 1.453 | 1.455 | | | |
| | 18.6 | 45.7 | 1.082 | 1.078 | | | |
| 30m more in vapor of aniline at 185°. | 18.1 | 72.7 | 2.189 | 2.189 | 5.18 | −0.0128 | 29.8 |
| | 18.1 | 63.2 | 1.861 | 1.863 | | | |
| | 18.1 | 56.0 | 1.604 | 1.602 | | | |
| | 18.1 | 48.0 | 1.294 | 1.294 | | | |
| 1h more in vapor of aniline at 185°. | 18.3 | 69.4 | 2.226 | 2.223 | 5.42 | −0.0122 | 25.9 |
| | 18.3 | 62.6 | 1.962 | 1.964 | | | |
| | 18.3 | 55.4 | 1.682 | 1.686 | | | |
| | 18.3 | 45.3 | 1.256 | 1.254 | | | |
| 1h more in vapor of aniline at 185°. | 19.2 | 73.5 | 2.452 | 2.450 | 5.64 | −0.0122 | 24.7 |
| | 19.3 | 66.2 | 2.155 | 2.158 | | | |
| | 19.2 | 57.6 | 1.806 | 1.807 | | | |
| | 19.3 | 48.7 | 1.415 | 1.414 | | | |

TABLE 24.—*Hard steel annealed at* 185°.

[Rod No. 36. $2\rho$=0.0481.]

| Remarks. | $t$ | $T$ | $e:10^3$ observed. | $e:10^3$ calculated. | $a$ | $b$ | $\alpha$ |
|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^2}$ °C. microvolt. |
| Glass-hard | 20.3 | 51.2 | −0.279 | −0.279 | −0.05 | −0.0121 | 37.17 |
| | 20.4 | 46.6 | −0.222 | −0.222 | | | |
| | 20.3 | 41.8 | −0.171 | −0.170 | | | |
| | 20.4 | 38.6 | −0.137 | −0.138 | | | |
| 10m in vapor of aniline at 185°. | 19.2 | 71.8 | 2.069 | 2.071 | 4.76 | −0.0081 | 25.85 |
| | 19.2 | 63.7 | 1.793 | 1.787 | | | |
| | 19.2 | 57.4 | 1.552 | 1.555 | | | |
| | 19.2 | 49.4 | 1.251 | 1.250 | | | |
| 20m more in vapor of aniline at 185°. | 18.5 | 78.5 | 2.485 | 2.483 | 5.26 | −0.0115 | 24.91 |
| | 18.5 | 64.3 | 1.968 | 1.971 | | | |
| | 18.5 | 54.9 | 1.609 | 1.605 | | | |
| | 18.5 | 45.2 | 1.207 | 1.208 | | | |
| 30m more in vapor of aniline at 185°. | 17.8 | 78.8 | 2.605 | 2.603 | 5.50 | −0.0125 | 24.15 |
| | 17.9 | 65.2 | 2.115 | 2.108 | | | |
| | 17.9 | 55.5 | 1.726 | 1.720 | | | |
| | 17.9 | 44.7 | 1.259 | 1.262 | | | |
| 1h more in vapor of aniline at 185°. | 17.9 | 73.0 | 2.447 | 2.461 | 5.50 | −0.0106 | 23.58 |
| | 17.9 | 64.7 | 2.178 | 2.163 | | | |
| | 17.9 | 53.8 | 1.703 | 1.696 | | | |
| | 17.9 | 46.5 | 1.374 | 1.371 | | | |
| 1h more in vapor of aniline at 185°. | 19.2 | 68.3 | 2.327 | 2.325 | 5.74 | −0.0114 | 23.13 |
| | 19.3 | 58.0 | 1.880 | 1.876 | | | |
| | 19.2 | 52.6 | 1.632 | 1.641 | | | |
| | 19.3 | 44.7 | 1.273 | 1.269 | | | |

## AVIOR OF HARD STEEL ANNEALED IN MOLTEN LEAD (330°).

:om an inspection of the foregoing families of curves it appeared able, in view of this relatively high temperature, that annealing ts of great magnitude would occur during the first minutes of ex- re. Conformably herewith, the rods were subjected to 330° during ecutive intervals of $1^m$, $30^m$, and $1^h$, and examined at the end of of these times. The rods selected were:

No. 37; diameter $(2\rho)=0.0820$ cm.
No. 38; diameter $(2\rho)=0.0616$ cm.
No. 39; diameter $(2\rho)=0.0483$ cm.

ıe following results were obtained:

TABLE 25.—*Hard steel annealed at* 330°.

[Rod No. 37. $2\rho=0.0820$.]

| Remarks. | $t$ | $T$ | $\epsilon : 10^3$ observed. | $\epsilon : 10^3$ calculated. | $a$ | $b$ | $a_t$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^3}t$ *microhm.* | °C. |
| hard..... | 18.7 | 5d.1 | −0.248 | −0.248 | 0.00 | −0.0089 | 86.51 | 18 |
| | 18.8 | 52.7 | −0.215 | −0.215 | | | | |
| | 18.8 | 51.8 | −0.206 | −0.206 | | | | |
| molten lead at 330°. | 17.8 | 77.5 | 3.898 | 3.898 | 7.74 | −0.0126 | 18.96 | 18 |
| | 17.8 | 67.5 | 3.308 | 3.308 | | | | |
| | 17.8 | 59.2 | 2.800 | 2.799 | | | | |
| | 17.8 | 46.9 | 2.012 | 2.012 | | | | |
| re in molten lead 0°. | 18.5 | 86.7 | 4.491 | 4.491 | 7.77 | −0.0113 | 18.78 | 19 |
| | 18.5 | 75.2 | 3.806 | 3.808 | | | | |
| | 18.5 | 62.3 | 3.003 | 3.005 | | | | |
| | 18.5 | 50.7 | 2.252 | 2.251 | | | | |
| e in molten lead at | 18.9 | 69.0 | 3.471 | 3.458 | 7.71 | −0.096 | 18.78 | 19 |
| | 18.9 | 57.2 | 2.667 | 2.685 | | | | |
| | 18.9 | 47.6 | 2.045 | 2.038 | | | | |
| | 18.9 | 39.4 | 1.472 | 1.470 | | | | |

TABLE 26.—*Hard steel annealed at* 330°.

[Rod No. 38. $2\rho=0.0616$.]

| Remarks. | $t$ | $T$ | $\epsilon : 10^3$ observed. | $\epsilon : 10^3$ calculated. | $a$ | $b$ | $a_t$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^3}t$ *microhm.* | °C. |
| hard..... | 18.8 | 50.2 | −0.577 | −0.573 | −1.19 | −0.0093 | 40.38 | 18 |
| | 18.8 | 44.8 | −0.459 | −0.461 | | | | |
| | 18.8 | 39.6 | −0.357 | −0.360 | | | | |
| | 18.8 | 34.8 | −0.271 | −0.269 | | | | |
| molten lead at 330°. | 17.6 | 67.6 | 4.012 | 4.015 | 8.96 | −0.0111 | 17.55 | 18 |
| | 17.7 | 61.3 | 3.532 | 3.531 | | | | |
| | 17.7 | 58.1 | 2.998 | 2.998 | | | | |
| | 17.6 | 42.7 | 2.083 | 2.084 | | | | |
| re in molten lead 0°. | 18.8 | 87.8 | 5.470 | 5.470 | 9.24 | −0.0124 | 17.86 | 19 |
| | 18.9 | 78.4 | 4.413 | 4.417 | | | | |
| | 18.9 | 63.7 | 3.794 | 3.784 | | | | |
| | 18.9 | 50.3 | 2.631 | 2.633 | | | | |
| e in molten lead at | 19.1 | 84.4 | 5.204 | 5.201 | 9.39 | −0.0128 | 17.27 | 19 |
| | 19.1 | 63.3 | 3.649 | 3.649 | | | | |
| | 19.1 | 50.1 | 2.610 | 2.615 | | | | |
| | 19.1 | 41.7 | 1.936 | 1.932 | | | | |

TABLE 27.—*Hard steel annealed at 330°.*

[Wire No. 89. $2\rho$=0.0483.]

| Remarks. | $t$ | $T$ | $\epsilon : 10^3$ observed. | $\epsilon : 10^3$ calculated. | $a$ | $b$ | $\alpha$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^3 s}$ *microhm.* | °C. |
| Glass-hard | 18.0 | 53.8 | −0.254 | −0.254 | 0.08 | −0.0110 | 26.04 | 18 |
| | 18.1 | 50.7 | −0.221 | −0.221 | | | | |
| | 18.1 | 48.1 | −0.195 | −0.194 | | | | |
| 1m in molten lead at 330°. | 17.5 | 56.6 | 2.647 | 2.646 | 7.61 | −0.0114 | 18.30 | 18 |
| | 17.5 | 51.7 | 2.335 | 2.334 | | | | |
| | 17.5 | 45.8 | 1.948 | 1.948 | | | | |
| | 17.5 | 39.6 | 1.540 | 1.537 | | | | |
| 30m more in molten lead at 330°. | 19.1 | 85.6 | 4.372 | 4.372 | 7.76 | −0.0113 | 18.11 | 19 |
| | 19.1 | 72.9 | 3.610 | 3.615 | | | | |
| | 19.1 | 61.9 | 2.937 | 2.929 | | | | |
| | 19.1 | 50.4 | 2.180 | 2.182 | | | | |
| 1h more in molten lead at 330°. | 19.0 | 82.5 | 4.218 | 4.217 | 7.80 | −0.0115 | 18.02 | 19 |
| | 19.0 | 66.7 | 3.255 | 3.254 | | | | |
| | 19.0 | 57.8 | 2.687 | 2.687 | | | | |
| | 19.0 | 49.5 | 2.142 | 2.142 | | | | |

## GENERAL DISCUSSION OF THE RESULTS OF THIS ANNEALING.

*Digest.*—The results thus far given adequately exhibit the general physical character of the process of tempering. For the sake of clearness, and with a view of partially eliminating such discrepancies as are due to incidental errors, the three individual values of thermo-electric power and specific resistance for each of the temperatures of annealing will be combined and their mean chosen for discussion. We thus arrive at the following relations:

TABLE 28.—*Mean results:*

I.—*For annealing in vapor of boiling methyl alcohol* (66°).

| Time of annealing= | 0h | 1h | 2h | 3h |
|---|---|---|---|---|
| $a$= | −1.62 | −1.07 | −0.80 | −0.60 |

II.—*For annealing in steam* (100°).

| Time of annealing= | 0h | ½h | ¾h | 1h | 2h | 3h |
|---|---|---|---|---|---|---|
| $a$= | −0.91 | 0.17 | 0.95 | 1.50 | 2.08 | 2.36 |

III.—*For annealing in vapor of boiling aniline* (185°).

| Time of annealing= | 0h | ½h | ¾h | 1h | 2h | 3h |
|---|---|---|---|---|---|---|
| $a$= | −0.95 | 4.19 | 4.71 | 5.00 | 5.18 | 5.40 |

IV.—*For annealing in molten lead* (330°).

| Time of annealing= | 0h | ½h | ¾h | 2h | 3h |
|---|---|---|---|---|---|
| $a$= | −0.37 | 8.11 | 8.26 | 8.30 | |

*Deduction.*—If these functionalities are constructed graphically, as has been done in Fig. 10 (time as abscissa, thermo-electric constant as ordi-

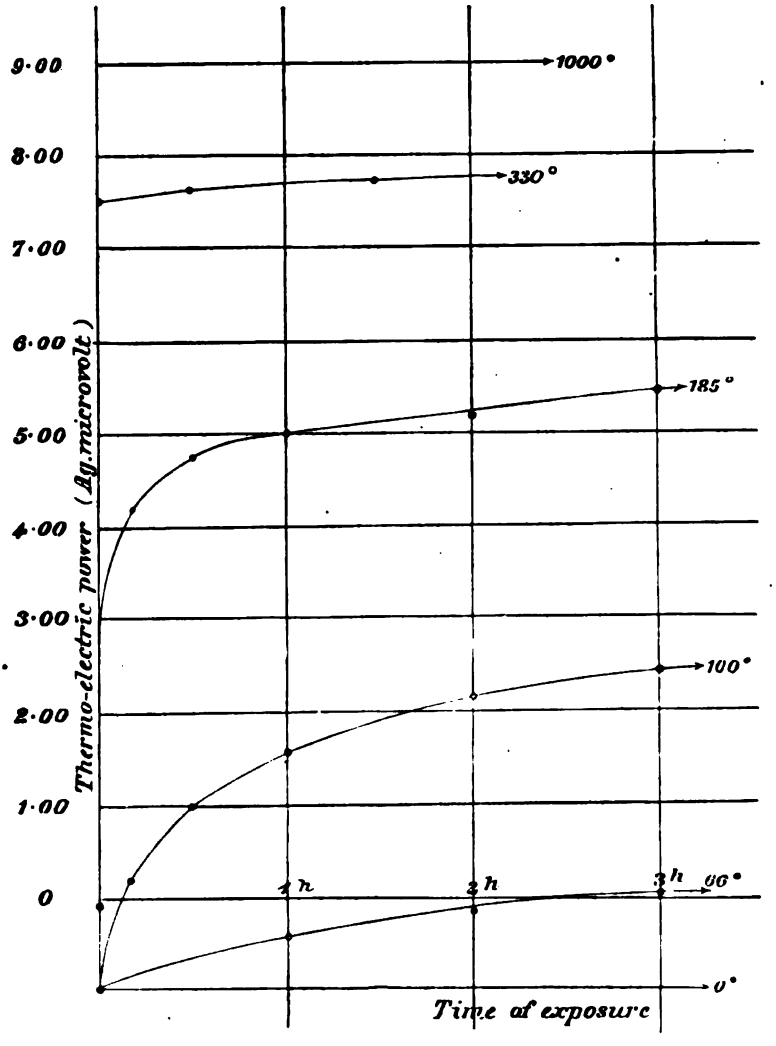



FIG. 10.—Hard wires annealed continuously at 0°, 66°, 100°, 185°, 330°, and 1,000°, respectively.

nate), we obtain a family of typical curves, the general character of which is distinctly pronounced and may be thus expressed:

The degree of hardness retained by a glass-hard rod, after having been subjected to the operation of annealing, is dependent both on the temperature to which it has been exposed and on the interval of time during which this exposure has taken place, in such a way that the effect of time, though of predominating importance in the case of small values of temperature, is more and more negligible in proportion as

these values increase. The operation is always most effective in its earlier stages, and this efficiency decreases very slowly where the temperatures are low—very rapidly, indeed almost suddenly, where they are high. If the action of any temperature be indefinitely prolonged, the rod under its influence ultimately reaches an inferior and limiting degree of hardness characteristic both of the temperature chosen and the type of steel under experiment. In other words: the annealing effect of any temperature increases gradually at a rate diminishing continuously through infinite time, very slowly in case of low temperature ($<100°$), with extreme rapidity in case of high temperature ($>200°$), so that the highest of the inferior states of hardness possible at any given temperature is approached asymptotically. The effect of the intensity of glass-hardness (strain) of the originally hard rod is not readily discernible.

The considerations set forth readily suggest the terminology: "*maximum of permanent hardness for the temperature t*"—an expression which will be used throughout the sequel to designate the highest of the inferior states of hardness, persistent at the said temperature, *t*.

The relatively large effect produced by low temperatures ($<100°$). when a glass-hard rod is subjected to their influence for a long period of time, is deserving of special mention. It follows that a perceptible annealing effect must be attainable with temperatures much lower than the lowest above employed; indeed that the only inferior limit in this respect is probably the temperature of the water in which the rod was originally chilled,—while even the chilled rod, though kept at constant temperature, cannot be regarded as existing in a state of thorough molecular equilibrium until the lapse of a considerable interval of time after the hardening has taken place. Herefrom it appears that in the thermo-electric experiments the danger of destroying the uniformity of temper of a glass-hard rod by overheating the hot junction is greatly to be apprehended. Quick work and low temperatures are, therefore, to be preferred at an unavoidable sacrifice of accuracy. Nor is soldering of the ends permissible, except with the most extreme and intelligent caution. We desire to advert, in conclusion, to the important bearing of this unlooked-for sensitiveness of hard steel, even to low temperatures, on all other physical properties depending on the temper of this material—permanent magnetism for instance. It is obvious that the nature of a purely magnetic phenomenon can only be satisfactorily investigated when the material carrying the magnetic quality, throughout the course of the experiments undergoes no permanent change, otherwise we virtually commence our investigation with one rod and finish it with another, obtaining data which are not immediately, if at all, comparable.

## ON THE EFFECT OF HIGHER AND OF LOWER TEMPERATURES ON THE TEMPER OF STEEL ORIGINALLY ANNEALED AT A GIVEN INTERMEDIATE TEMPERATURE.

*Effect of lower temperatures.*—The marked tendency of glass-hard rods to suffer diminution of hardness, even when exposed to temperatures but slightly above mean atmospheric temperature, naturally led to another important inquiry almost the converse of the preceding. We refer to the behavior of a rod annealed at a given temperature to the prolonged effect of lower temperatures subsequently applied.

For the purpose of obtaining experimental data a steel wire (No. 26, $2\rho=0.085$), which had on a former occasion been annealed in an oil bath at 250°, was exposed to steam at 100° for one hour. The results of the thermo-electric measurements made before and after this final exposure were these:

TABLE 29.—*Steel annealed at $t_2$° exposed to $t_1$°, $t_2 > t_1$*

| Before. | | | After. | | | |
|---|---|---|---|---|---|---|
| $t$ | $T$ | $e:10^2$ | $t$ | $T$ | $e:10^2$ | $e:10^2$ |
| 16.1 | 89.1 | 4.05 | 16.9 | 73.2 | 3.17 | (3.22) |
| 16.1 | 80.7 | 3.62 | 16.9 | 63.2 | 2.69 | (2.72) |
| 16.2 | 68.1 | 2.99 | 16.9 | 56.5 | 2.32 | (2.35) |
| 16.2 | 54.6 | 2.29 | 17.0 | 50.2 | 1.98 | (1.99) |
| 16.2 | 44.5 | 1.72 | | | | |
| 16.2 | 37.9 | 1.34 | | | | |

The temperatures $t$ in both series are approximately identical. The electromotive force $e$ may therefore be regarded as dependent on the difference of temperature $T-t$ only,[30] and with this presumption graphically represented. If, with the object of interpolating graphically, the two curves be carefully constructed, and the values of $e$ for the temperatures of the one set of observations be derived from the curve for the other, then a comparison of corresponding values of $e$ shows clearly that no annealing due to 100° is appreciable. In the table (29) the interpolated electromotive forces are distinguished by parentheses.

[30] For $e=a(T-t)+b(T^2-t^2)=(T-t)(a+b[T-t]+2bt)=f(T-t)$ if $t$ is constant.

This result was corroborated by a second experiment made in the same way with rod No. 27 ($2\rho=0.085$), which had been annealed in oil at 200°. The thermo-electric data obtained before and after the final annealing at 100° were:

TABLE 30.—*Steel annealed at $t_2°$ exposed to $t_1°$, $t_2>t_1$.*

| Before. | | | After. | | | |
|---|---|---|---|---|---|---|
| $t$ | $T$ | $e:10^3$ | $t$ | $T$ | $e:10^3$ | $e:10^3$ |
| 16.3 | 88.5 | 2.62 | 17.0 | 84.2 | 2.45 | (2.45) |
| 16.4 | 80.8 | 2.38 | 17.0 | 71.7 | 2.08 | (2.08) |
| 16.4 | 70.0 | 2.06 | 17.1 | 62.3 | 1.76 | (1.77) |
| 16.4 | 61.6 | 1.77 | 17.2 | 43.4 | 1.09 | (1.09) |
| 16.4 | 53.1 | 1.48 | | | | |
| 16.4 | 46.4 | 1.22 | | | | |

Plainly these results admit of the following generalized interpretation: A steel rod, annealed at a given temperature, will remain the more nearly passive as regards the effect of an inferior temperature, the lower its value and the shorter its time of application on the one hand, and the nearer the mechanical state of the rod to the limit of hardness for the said temperature on the other. Where the limit in question has been fully reached the rod is unaffected by the action of lower temperature, however prolonged.

*Effect of higher temperatures.*—There is another question of a similarly important bearing on the nature of the phenomena of annealing. In the above we drew the general inference that in the case of a given rod possessing a given degree of glass-hardness, the mechanical state resulting after annealing is dependent on the temperature and the time of exposure only; that when the latter is indefinitely prolonged, a particular and characteristic limit of hardness is reached for each temperature of the annealing bath. If this be the case, then it must be immaterial, in so far as the identity of the final states is concerned, whether, for instance, a rod is first annealed in steam at 100° and then in aniline vapor at 185° to a limit, or whether it is annealed to a limit in aniline vapor at once. In other words, the maximum reduction of hardness attainable by the action of any given temperature on glass-hard steel is independent of the manner of variation of hardness (the path as it were) by which this final state is reached. On this point the following experiments were made:

Three steel wires of different thicknesses (Nos. 40, 41, 42), carefully tested for longitudinal homogeneity, were first examined in the glass-hard state. They were then broken in two, and one of the halves of each was annealed directly in aniline vapor at 185° for 10 minutes; the others, however, were first exposed in steam at 100° for 40 minutes, and after this, as in the former case, for 10 minutes in aniline. Hereupon the six rods were tested for hardness, with the following results. It

was expedient to make measurements of resistance only, Hockin and Matthiessen's method being employed:

| In steam and in aniline vapor. | | In aniline vapor only. | |
|---|---|---|---|
| Rod No. 40 ($2\rho$=0. 085) | Glass-hard..$s$=41. 8 | $s$=40. 6 | ($t$=14°) |
| | Annealed...$s$=31. 0 | $s$=30. 6 | ..... |
| Rod No. 41 ($2\rho$=0. 064) | Glass-hard..$s$=43. 0 | $s$=42. 9 | ($t$=14°) |
| | Annealed...$s$=30. 0 | $s$=29. 8 | ..... |
| Rod No. 42 ($2\rho$=0. 049) | Glass-hard..$s$=36. 4 | $s$=36. 5 | ($t$=14°) |
| | Annealed...$s$=26. 0 | $s$=26. 0 | ..... |
| Mean | Glass-hard..$s$=40. 2 | $s$=40. 0 | ($t$=14°) |
| | Annealed...$s$=29. 0 | $s$=28. 8 | ..... |

A second experiment was made with three other wires (Nos. 43, 44, 45). After the hardness for the glass-hard state had been obtained, the rods were again broken in two; one of the halves of each was annealed for 40 minutes in ethylic alcohol vapor at 78°, and then for 6 hours in steam; the others in steam only during the same interval. The results obtained are these:

| In vapor of alcohol and in steam. | | In steam only. | |
|---|---|---|---|
| Rod No. 43 ($2\rho$=0. 085) | Glass-hard..$s$=40. 2 | $s$=40. 6 | ($t$=10°) |
| | Annealed...$s$=31. 9 | $s$=31. 8 | ..... |
| Rod No. 44 ($2\rho$=0. 066) | Glass-hard..$s$=40. 5 | $s$=41. 2 | ($t$=10°) |
| | Annealed...$s$=29. 4 | $s$=29. 8 | ..... |
| Rod No. 45 ($2\rho$=0. 049) | Glass-hard..$s$=35. 5 | $s$=35. 8 | ($t$=10°) |
| | Annealed..$s$=27. 5 | $s$=27. 9 | ..... |
| Mean | Glass-hard..$s$=38. 7 | $s$=39. 2 | ($t$=10°) |
| | Annealed..$s$=29. 8 | $s$=29. 7 | ..... |

Both of these series of experiments are in perfect accord, and we therefore infer: The specific effect of a given temperature of annealing on the state of hardness of steel is independent of the possibly pre-existing effects of a lower temperature, to the extent that the result of the influence of the latter is the more fully annulled the greater the period of action of the former.

*Anomalous feature.*—This result is remarkable, inasmuch as by a sudden exposure of a glass-hard rod to (high) temperature, a very large amount of potential energy is *instantaneously* released. If, therefore, two identical glass-hard wires be annealed, the one by raising the temperature very gradually as far as $t^0$, the other by being suddenly exposed to $t^0$, we would infer, *ceteris paribus*, that a difference of hardness must result. For, in view of the sudden conversion of the available mechanical energy into heat in the latter case, we anticipate an equivalent increase in the temperature of the rod. Virtually, therefore, this steel is annealed at a temperature somewhat above that of the annealing bath, or above that of the other rod. So far as our experiments went this was not detected; but the test made is not exhaustive. Our attention was centered on other matters at the time. Possibly, however, the anomalous distribution of hardness obtained by annealing in oil may be partially accounted for in this way.

## BEHAVIOR OF SOFT STEEL RODS.

*Object of the measurement.*—The above values for thermo-electric power all refer to elements in which steel is thermo-electrically combined with pure soft silver; but the latter metal, though chosen expediently, is otherwise arbitrary and without inherent bearing on the subject in hand. We will undoubtedly obtain data more in harmony with the purpose of the present investigation, and far more readily intelligible, by eliminating this foreign metal from our considerations entirely. It is to be our endeavor throughout the following paragraphs not only to add to the perspicuity of our data, but also to give them possibly immediate theoretical significance, by referring all measurements to a particular and normal state of steel. The soft state would appear to suggest itself in so far as it occupies an extreme and inferior position in the scale. If, however, this is to be chosen as a point of departure, the rods in this state should possess normal and fixed thermo-electric qualities, even for different kinds of steel. This is by no means the case, as the special experiments presently to be detailed will show. Indeed, even in the case of soft rods nominally of the same material, at all events nearly of identical composition, the difference of thermo-electric power is often very marked.

*Method of softening.*—With the object of reaching extreme values of the soft state, the rods were embedded in artificial powdered ferro-ferric oxide, as it falls from the anvil, and surrounded by a closed gas-pipe; the latter in turn enveloped in a thick coating of fire-clay, protected externally with thin sheet-iron. The whole was heated to intense redness, and then allowed to cool very slowly in the ashes of the smoldering fire[31]. The non-conducting envelopes insured a very gradual subsidence of temperature.

*Data for soft steel and for soft iron.*—As examples the results obtained with rods Nos. 46, 47, and 48 will be given:

TABLE 31.—*Behavior of soft steel rods.*

| Remarks. | $t$ | $T$ | $e$ observed. | $e$ calculated. | $a$ | $b$ | $ax$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^2}$ *microhm.* | °C. |
| No. 46. $2\rho=0.0843$ ..... | 18.7 | 87.7 | 486.3 | 486.2 | 8.33 | −0.0121 | 17.08 | 19 |
| | 18.7 | 67.3 | 354.8 | 354.5 | | | | |
| | 18.7 | 54.2 | 264.0 | 264.6 | | | | |
| | 18.7 | 45.5 | 202.8 | 202.6 | | | | |
| No. 47. $2\rho=0.0625$ ..... | 23.0 | 85.7 | 543.5 | 544.8 | 10.17 | −0.0137 | 15.09 | 19 |
| | 22.7 | 68.1 | 406.9 | 405.5 | | | | |
| | 22.6 | 51.7 | 266.9 | 266.4 | | | | |
| | 22.4 | 40.6 | 169.0 | 169.3 | | | | |
| No. 48. $2\rho=0.0485$ ..... | 19.0 | 84.0 | 474.7 | 472.5 | 8.52 | −0.0121 | 16.41 | 19 |
| | 19.0 | 64.3 | 338.4 | 340.1 | | | | |
| | 19.0 | 50.8 | 242.6 | 243.9 | | | | |
| | 19.0 | 37.9 | 148.9 | 148.0 | | | | |

[31] With regard to the decarbonization possible or incident to this operation see Chapter III.

For the sake of comparison iron wires of different kinds were treated in the same way and subsequently examined. The results obtained with Nos. I, II, and III will be cited as examples:

TABLE 32.—*Behavior of soft iron wire.*

| Remarks. | $t$ | $T$ | $\epsilon$ observed. | $\epsilon$ calculated. | $a$ | $b$ | $s_t$ | $t$ |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolt.* | *microvolt.* | *microvolt.* | *microvolt.* | $\frac{cm}{cm^2 t}$ *microhm.* | °C. |
| No. I. $2\rho$=0.0966 ..... | 18.7 | 79.6 | 581.3 | 582.0 | | | | |
| | 18.8 | 66.3 | 465.4 | 464.9 | 11.25 | −0.0174 | 13.02 | 19 |
| | 18.7 | 54.3 | 356.3 | 355.8 | | | | |
| | 18.8 | 44.9 | 264.7 | 265.0 | | | | |
| No. II. $2\rho$=0.0630 ..... | 18.6 | 78.0 | 550.2 | 549.5 | | | | |
| | 18.6 | 64.2 | 430.1 | 430.3 | 10.56 | −0.0135 | 12.74 | 19 |
| | 18.6 | 53.4 | 332.6 | 333.6 | | | | |
| | 18.6 | 43.4 | 241.6 | 241.1 | | | | |
| No. III. $2\rho$=0.0312 ..... | 18.5 | 86.9 | 560.2 | 560.0 | | | | |
| | 18.5 | 68.1 | 418.0 | 419.1 | 9.66 | −0.0140 | 13.87 | 19 |
| | 18.5 | 54.3 | 310.3 | 309.3 | | | | |
| | 18.5 | 40.1 | 190.7 | 190.9 | | | | |

*Impurities in steel and iron.*—Now, there is reason to suppose that in the case of iron carburets generally the electrical effect of foreign impurities is partially masked by the phenomenally great effect of combined carbon.[32] Conformably with the usually accepted views, therefore, the shifting of thermo-electric position due to the presence in iron of materials (S., P., Si., etc.) other than carbon will be particularly marked for the soft states. For it is here that the quantity of combined carbon contained is at a minimum, while the steel itself is in a natural homogeneous state. We have analogies in the case of alloys. For instance, on alloys of gold and silver small additional quantities of foreign admixtures are relatively without marked electrical effect, whereas if pure gold or pure silver be adulterated with the same quantities of the same material the result is pronounced. If we compare the values of $a$ and $s$ for soft iron with those obtained for soft steel the specific effect of carbon is strikingly obscure. We are induced to refer the comparatively small differences apparent to the effect of foreign impurities in the iron. At least, in contrast with the phenomenal electrical interval between the glass-hard and the soft states of steel, the electrical effect of carbon is here wholly masked by that of the incidental ingredients. But it is herewith fully demonstrated that the steel rod possessing the qualities of a normal must be sought for elsewhere than in the soft state.

[32] Directly or indirectly. It will be shown in the sequel that the electrical variation discussed in this chapter is probably due to the strain accompanying hardness, but this in its turn is conditioned by the presence of carbon in iron.

## THE RELATION EXISTING BETWEEN THE THERMO-ELECTRIC POWER AND THE SPECIFIC RESISTANCE OF STEEL.

*Reduction of data.*—In the above experiments we have thus far met with 86 pairs of correlative values of specific resistance and thermo-electric constant. We will supplement these results by values obtained with four rods subjected to six hours of annealing in steam. They are as follows:

| Rod. | $2\rho$ | $a$ | $s_t$ | $t$ |
|---|---|---|---|---|
| No. 49..... | 0.0574 | 1.90 | 35.75 | 19 |
| No. 50..... | 0.0554 | 4.08 | 29.34 | 19 |
| No. 51..... | 0.0531 | 4.06 | 27.08 | 19 |
| No. 52..... | 0.0344 | 3.90 | 28.68 | 19 |

In all, therefore, we are in possession of 90 pairs of values. These amply suffice to decide in how far an intrinsic relation between thermo-electric power and specific resistance, in case of one and the same metal (steel), in different states of temper, demonstrably exists. Now we have

$$\left(\frac{de}{d(T-t)}\right)_{T=t}=a;$$

whence it appears that the thermo-electric constant $a$ primarily refers to the temperature zero, centigrade. It is, therefore, consistent to reduce the observed values of specific resistance (18°—21°) to the same temperature (zero). This is at best a laborious piece of work, and moreover presupposes a knowledge of the relation of resistance and temperature (the coefficients vary within the large range of 0.1 per cent. nearly to above 0.4 per cent.) for each of the 90 degrees of hardness encountered. But with the aid of the results contained in Chapter I of the present memoir this reduction may be satisfactorily made. The results are given in the following table, where $s_t=s(1+\alpha t)$:

TABLE 33.—*Specific resistance (cm/cm³ 0° microhm) of steel.*

| No. | $s_t$ | t | $\alpha\times10^3$ | s | No. | $s_t$ | t | $\alpha\times10^3$ | s | No. | $s_t$ | t | $\alpha\times10^3$ | s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 18.96 | 19 | 3.4 | 17.81 | 29 | 41.32 | 19 | 1.7 | 40.03 | 35 | 28.58 | 20 | 2.4 | 27.27 |
| 2 | 18.49 | 19 | 3.5 | 17.34 | 30 | 37.08 | 18 | 1.8 | 35.92 | 35 | 27.26 | 19 | 2.5 | 26.03 |
| 3 | 20.54 | 19 | 3.1 | 19.40 | 30 | 36.80 | 18 | 1.9 | 35.58 | 35 | 26.04 | 19 | 2.6 | 24.81 |
| 4 | 20.00 | 19 | 3.3 | 18.22 | 30 | 36.51 | 18 | 1.9 | 35.30 | 35 | 25.29 | 18 | 2.7 | 24.11 |
| 5 | 17.64 | 19 | 3.6 | 16.51 | 30 | 36.42 | 19 | 1.9 | 35.15 | 35 | 24.72 | 18 | 2.7 | 23.57 |
| 6 | 20.75 | 20 | 3.2 | 19.51 | 31 | 40.47 | 21 | 1.7 | 39.08 | 36 | 37.17 | 21 | 1.8 | 35.82 |
| 7 | 22.74 | 19 | 2.9 | 21.55 | 31 | 39.05 | 20 | 1.8 | 37.70 | 36 | 25.85 | 20 | 2.6 | 24.58 |
| 8 | 23.20 | 19 | 2.9 | 21.99 | 31 | 37.64 | 19 | 1.8 | 36.40 | 36 | 24.91 | 19 | 2.7 | 23.69 |
| 9 | 20.47 | 19 | 3.2 | 19.30 | 31 | 36.33 | 19 | 1.9 | 35.06 | 36 | 24.15 | 19 | 2.8 | 22.93 |
| 10 | 25.67 | 19 | 2.6 | 24.46 | 31 | 35.38 | 18 | 1.9 | 34.21 | 36 | 23.58 | 18 | 2.9 | 22.41 |
| 11 | 24.81 | 19 | 2.7 | 23.60 | 31 | 34.72 | 18 | 2.0 | 33.50 | 36 | 23.12 | 18 | 2.9 | 21.97 |
| 12 | 22.93 | 19 | 2.9 | 21.73 | 32 | 41.42 | 21 | 1.7 | 39.99 | 37 | 36.51 | 18 | 1.9 | 35.30 |
| 13 | 20.66 | 19 | 3.2 | 19.48 | 32 | 39.53 | 20 | 1.7 | 38.23 | 37 | 18.96 | 18 | 3.4 | 17.87 |
| 14 | 27.36 | 20 | 2.5 | 26.06 | 32 | 38.02 | 19 | 1.8 | 36.76 | 37 | 18.78 | 19 | 3.4 | 17.64 |
| 15 | 28.11 | 19 | 2.4 | 26.88 | 32 | 36.33 | 19 | 1.9 | 35.06 | 37 | 18.78 | 19 | 3.4 | 17.64 |
| 16 | 26.70 | 19 | 2.5 | 25.49 | 32 | 35.19 | 18 | 1.9 | 34.03 | 38 | 40.38 | 18 | 1.7 | 39.17 |
| 17 | 27.93 | 19 | 2.4 | 26.71 | 32 | 34.34 | 18 | 2.0 | 33.14 | 38 | 17.55 | 18 | 3.6 | 16.48 |
| 18 | 31.32 | 19 | 2.2 | 30.06 | 33 | 36.98 | 21 | 1.8 | 35.64 | 38 | 17.36 | 19 | 3.6 | 16.25 |
| 19 | 28.68 | 19 | 2.4 | 27.43 | 33 | 35.09 | 20 | 1.9 | 33.72 | 38 | 17.25 | 19 | 3.6 | 16.16 |
| 20 | 24.34 | 19 | 2.8 | 23.11 | 33 | 33.58 | 19 | 2.0 | 32.35 | 39 | 36.04 | 18 | 1.9 | 34.85 |
| 21 | 29.34 | 19 | 2.3 | 28.11 | 33 | 32.26 | 19 | 2.1 | 31.02 | 39 | 18.30 | 18 | 3.5 | 17.22 |
| 22 | 30.94 | 19 | 2.2 | 29.70 | 33 | 31.22 | 18 | 2.2 | 30.03 | 39 | 18.11 | 19 | 3.5 | 16.98 |
| 23 | 27.93 | 19 | 2.4 | 26.71 | 33 | 30.67 | 18 | 2.2 | 29.49 | 39 | 18.02 | 19 | 3.5 | 16.89 |
| 28 | 42.64 | 18 | 1.6 | 41.45 | 34 | 39.34 | 21 | 1.7 | 37.98 | 46 | 17.08 | 19 | 3.6 | 15.98 |
| 28 | 42.55 | 18 | 1.6 | 41.36 | 34 | 29.25 | 20 | 2.3 | 27.96 | 47 | 15.09 | 19 | 3.9 | 14.05 |
| 28 | 42.45 | 19 | 1.6 | 41.20 | 34 | 28.02 | 19 | 2.4 | 26.80 | 48 | 16.41 | 19 | 3.7 | 15.34 |
| 28 | 42.55 | 19 | 1.6 | 41.30 | 34 | 27.17 | 19 | 2.5 | 25.94 | 49 | 35.75 | 19 | 1.9 | 34.51 |
| 29 | 42.08 | 17 | 1.6 | 40.95 | 34 | 26.32 | 18 | 2.6 | 25.14 | 50 | 29.34 | 19 | 2.3 | 28.11 |
| 29 | 41.70 | 18 | 1.6 | 40.53 | 34 | 25.85 | 18 | 2.6 | 24.69 | 51 | 27.08 | 19 | 2.5 | 25.85 |
| 29 | 41.52 | 19 | 1.7 | 40.12 | 35 | 42.45 | 21 | 1.6 | 41.07 | 52 | 28.68 | 19 | 2.4 | 27.43 |

*Fundamental constants.*—For the sake of greater clearness in designation, let $a$ be replaced by $y'$, $s_0$ by $x$. Parallel variations of $y'$ and $x$ we have had frequent occasion to notice. But we have now the data in hand for a complete discussion of the nature of their mutual dependence, and this will manifest itself perspicuously and at once in a graphic representation with $x$ as abscissa, $y'$ as ordinate. Figure 11 contains the 90 points in question. They lie within a band or pathway which, as a rule, is narrow, especially so near its middle, but widens somewhat as we approach the lower extremity, where $y'=0$. Nevertheless, the character of the functionality involved within the given range of possible variation appears with due prominence. *It is unquestionably linear.*

We may, therefore, with great probability premise that between $y'$ and $x$ a relation of the form

$$y'=m-nx \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

exists. If we make this equation the basis of a calculation in which the fundamental constants $m$ and $n$ are to be determined by the method of least squares we arrive at the values

$$m=15.176 \qquad n=0.4123$$

by solving the normal equations

$$P=mA-nB \qquad Q=mB-nC$$

where

$$A=\Sigma X^0 = 90$$
$$B=\Sigma X = 2536.55$$
$$C=\Sigma X^2 = 773.21$$
$$P=\Sigma y^1 = 319.91$$
$$Q=\Sigma X y^1 = 6612.1.$$

*New thermo-electric data.*—Of these constants, $m$ commands only secondary interest, in so far as it depends on the metal (silver in our case)

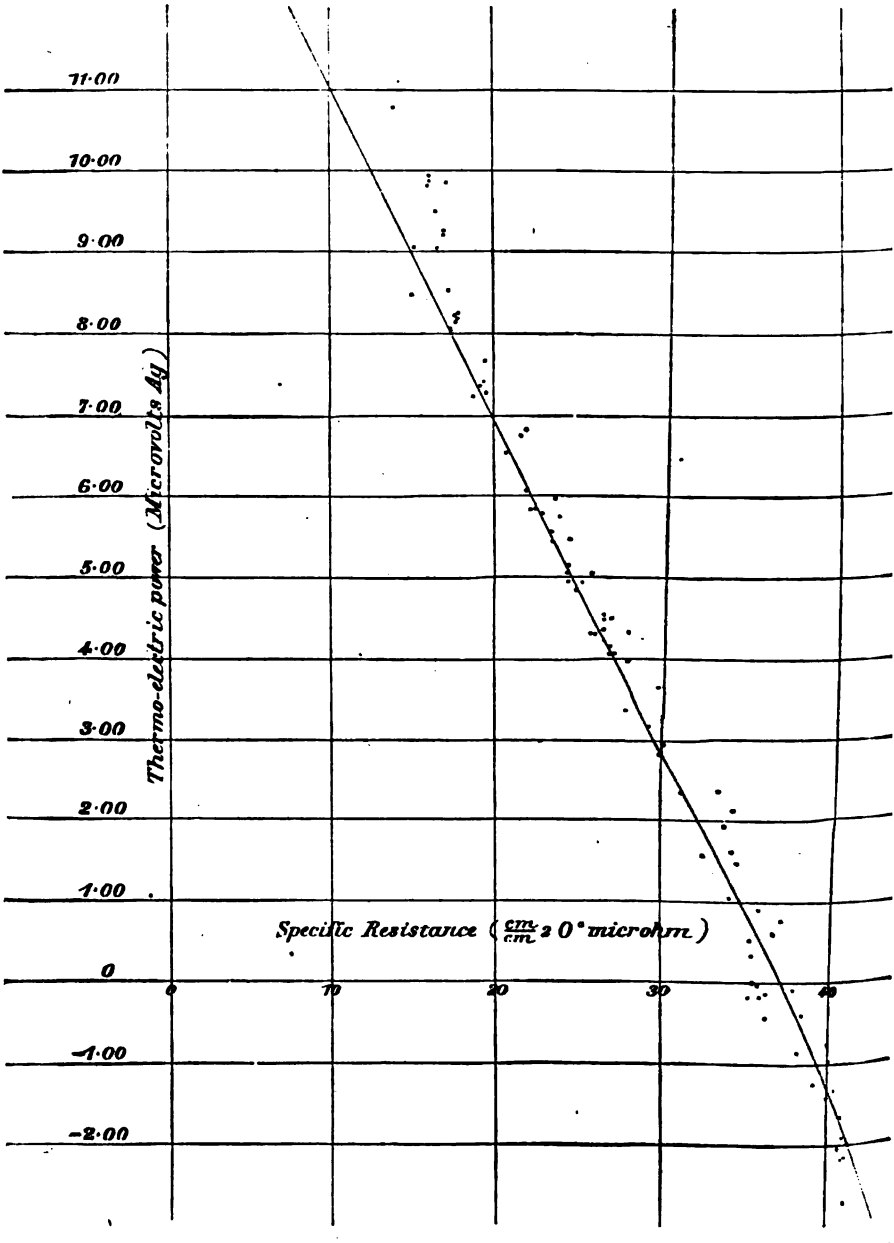



FIG. 11.—Diagram of the relation between the thermo-electric power of steel in different states of temper, and its specific resistance.

arbitrarily chosen to fix a datum or point of departure for thermo-electric measurements. This, however, is not true of $m-y'$, a quantity wholly

*independent* of the arbitrary element in question. It therefore appears expedient to select $m-y'=h$ as a new thermo-electric variable, in which case (1) reduces to the simpler form $h=nx$. The new thermo-electric data ($h$, $nx$) thus obtained are exclusively dependent on qualities inherent in steel. They have no reference to metals (silver) foreign to the present purpose. From a mathematical standpoint $m$ is the experimental constant by which a specially selected set of co-ordinates is determined. From a physical standpoint $m$ would represent the thermo-electric constant of a couple, one member of which is silver, the other the imaginary steel rod, whose specific resistance, supposed diminishable indefinitely in accordance with the above law, is zero. It is this initial state of hardness ($h=o$) at which the new variable $h$ originates.

*Thermo-electric hardness defined.*—The new thermo-electric variable, $h$, will, throughout the present memoir, be designated by the term *thermo-electric hardness*. The introduction of this quantity was suggested to us by considerations similar to those which led to the conception of absolute temperature. To the absolute zero of temperature, however, Thomson has been able to give a concrete physical interpretation; whereas the zero of thermo-electric hardness, so far as the results of the present chapter go, furnishes no more than a point of departure, at once convenient and free from arbitrary assumptions. It is hardly necessary to cite as a second example the hypothesis defining the modulus of elasticity, for instance.

The following is a brief summary of the advantages immediately derived from the introduction of thermo-electric hardness:

1. Hardness in the case of steel is expressed for the soft as well as for the hard rod in significant and at the same time convenient figures, which increase as this quality increases. The scale is, therefore, adapted to circumstances.

2. A change of signs is avoided, the current invariably flowing from the given specimen through hot to the normal. In other words, the normal is thermo-electrically positive to the whole family of iron-carburets, iron, steel and cast iron, no matter what be their mechanical state.

3. The results are independent of the shiftings of thermo-electric position common to all metals, due to small amounts of impurity or difference of mechanical state.

4. By the aid of the coefficients discussed in chapter I and for the sake of concreteness of conception only, we may state that, theoretically, the normal condition of steel, to which thermo-electric hardness refers, would nearly be given by soft steel cooled down as far as the absolute zero of temperature. (See Chapter III.)

*Tabular comparisons.*—A complete table follows, showing the differences between observed ($h=m-y'$) and calculated ($nx$) values of thermo-

electric hardness. As has been stated, the results are deduced by the method of least squares:

TABLE[31] 34.—*Comparison of the values of the thermo-electric hardness and specific resistance.*

| No. | h | nx | Diff. | No. | h | nx. | Diff. | No. | h | nx | Diff. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.38 | 7.34 | 0.04 | 29 | 15.88 | 16.50 | —0.62 | 35 | 10.96 | 11.24 | —0.28 |
| 2 | 7.15 | 7.15 | 0.00 | 30 | 15.60 | 14.81 | 0.79 | 35 | 10.43 | 10.73 | —0.30 |
| 3 | 8.19 | 8.00 | 0.19 | 30 | 15.19 | 14.67 | 0.52 | 35 | 10.00 | 10.23 | —0.23 |
| 4 | 7.40 | 7.76 | —0.36 | 30 | 14.88 | 14.56 | 0.32 | 35 | 9.76 | 9.94 | —0.18 |
| 5 | 6.66 | 6.81 | —0.15 | 30 | 14.71 | 14.49 | 0.22 | 35 | 9.54 | 9.72 | —0.18 |
| 6 | 7.94 | 8.04 | —0.10 | 31 | 16.38 | 16.11 | 0.27 | 36 | 15.23 | 14.77 | 0.46 |
| 7 | 9.03 | 8.88 | 0.15 | 31 | 15.26 | 15.54 | —0.28 | 36 | 10.42 | 10.12 | 0.30 |
| 8 | 8.72 | 9.07 | —0.35 | 31 | 14.63 | 15.01 | —0.38 | 36 | 9.92 | 9.77 | 0.15 |
| 9 | 8.22 | 7.96 | 0.26 | 31 | 14.32 | 14.45 | —0.13 | 36 | 9.68 | 9.45 | 0.23 |
| 10 | 10.51 | 10.08 | 0.43 | 31 | 13.63 | 14.10 | —0.47 | 36 | 9.68 | 9.24 | 0.44 |
| 11 | 10.08 | 9.73 | 0.30 | 31 | 13.37 | 13.82 | —0.45 | 36 | 9.44 | 9.06 | 0.38 |
| 12 | 8.78 | 8.96 | —0.18 | 32 | 16.62 | 16.49 | 0.13 | 37 | 16.18 | 14.56 | 0.62 |
| 13 | 8.29 | 8.03 | 0.26 | 32 | 15.57 | 15.76 | —0.19 | 37 | 7.44 | 7.37 | 0.07 |
| 14 | 11.12 | 10.74 | 0.38 | 32 | 14.38 | 15.16 | 0.78 | 37 | 7.41 | 7.27 | 0.14 |
| 15 | 11.33 | 11.08 | 0.25 | 32 | 13.79 | 14.45 | —0.66 | 37 | 7.47 | 7.27 | 0.20 |
| 16 | 10.51 | 10.51 | 0.00 | 32 | 13.17 | 14.03 | —0.86 | 38 | 16.37 | 16.15 | 0.22 |
| 17 | 10.92 | 11.01 | —0.09 | 32 | 12.92 | 13.66 | —0.74 | 38 | 6.22 | 6.79 | —0.57 |
| 18 | 12.89 | 12.89 | 0.00 | 33 | 15.25 | 14.69 | 0.56 | 38 | 5.94 | 6.78 | —0.78 |
| 19 | 11.35 | 11.31 | 0.04 | 33 | 14.21. | 13.90 | 0.31 | 38 | 5.79 | 6.66 | —0.87 |
| 20 | 9.78 | 9.53 | 0.20 | 33 | 13.68 | 13.34 | 0.34 | 39 | 15.10 | 14.37 | 0.73 |
| 21 | 11.42 | 11.59 | —0.17 | 33 | 12.93 | 12.79 | 0.14 | 39 | 7.57 | 7.10 | 0.47 |
| 22 | 11.77 | 12.25 | —0.48 | 33 | 12.51 | 12.38 | 0.13 | 39 | 7.42 | 7.00 | 0.42 |
| 23 | 10.94 | 11.01 | —0.07 | 33 | 12.18 | 12.16 | 0.02 | 39 | 7.38 | 6.97 | 0.41 |
| 24 | 17.74 | 17.09 | 0.65 | 34 | 16.01 | 15.66 | 0.35 | 46 | 6.85 | 6.59 | 0.26 |
| 25 | 17.12 | 17.05 | 0.07 | 34 | 11.59 | 11.53 | 0.06 | 47 | 5.01 | 5.79 | —0.78 |
| 26 | 16.99 | 16.99 | 0.00 | 34 | 11.08 | 11.05 | 0.03 | 48 | 6.66 | 6.32 | 0.34 |
| 28 | 16.76 | 17.03 | —0.27 | 34 | 10.85 | 10.69 | 0.16 | 49 | 13.28 | 14.23 | —0.95 |
| 29 | 17.08 | 16.89 | 0.19 | 34 | 10.57 | 10.37 | 0.20 | 50 | 11.10 | 11.59 | —0.49 |
| 29 | 16.43 | 16.71 | —0.28 | 34 | 10.34 | 10.18 | 0.16 | 51 | 11.12 | 10.66 | 0.46 |
| 29 | 16.09 | 16.54 | —0.45 | 35 | 17.15 | 16.93 | 0.22 | 52 | 11.28 | 11.31 | —0.03 |

[31] The second decimal place ($h$, $nx$, diff.) serves only, of course, to give greater accuracy to the first and might perhaps have been advantageously suppressed.

*Distribution of errors.*—If this series of results is examined critically, that is with especial reference to magnitude and location of the errors, relatively large discrepancies encountered at the beginning of the table, in the case of very soft rods, are conspicuous. It is not, therefore, to be considered as finally decided whether the relation $h=f(x)$ may not for small values of $x$ be other than linear; such, however, as rapidly to approximate to the latter form of function as $x$ increases. The other errors in general are as liable to assume positive as negative values; they lie within sufficiently narrow limits, and do not, with one exception, exhibit any characteristic progress for consecutive states. In the case of wires annealed in methyl alcohol a uniform succession of errors is, however, apparent. For continually decreasing values of $h$ we have:

| | | | | |
|---|---|---|---|---|
| No. 28..... | 7 | 1 | 0 | —3 |
| No. 29..... | 2 | —3 | —5 | —6 |
| No. 30..... | 8 | 5 | 3 | 2 |

In other words, with continually augmenting time of exposure, the temperature, 66°, produces an annealing effect such that the linear relation between thermo-electric hardness and specific resistance is not rigidly maintained. Here we have unquestionably the evidences of a

structural phenomenon. The inference is plausible that the annealing influence of this comparatively low temperature is largely confined to those parts of the rod where the strain is most intense. This is probably the case with the superficial layers; for, according to Fromme's datum the density of these has been increased enormously. Now, it would seem that it is upon the surface layers of a rod that thermo-electric power is principally dependent, whereas specific resistance varies with the mean hardness of rod taken as a whole. The discrepancy in question is repeated with such uniformity in each of the three wires, that it is obvious we have in hand more than a mere error of observation. Furthermore, the similar variation which occurs in the case of wires annealed at 100° shows that the anomaly exists in steel itself, and is deserving of special inquiry.

*Consequences of an elementary law, $h=ns$.*—A more detailed analysis of the thermo-electric effects of structure does not substantiate the stated inference that the thermo-electric data are influenced to a greater extent by the condition of the surface layers of steel than the resistance data.

From the very general evidence obtained in Table 34 in favor of the law $h=ns$, we are justified in giving it fundamental or elementary importance. In other words, the supposition is warranted that, for each of the coaxial necessarily homogeneous elementary shells of which we may suppose the rod to be made up, the relation

$$h=ns \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

applies. Suppose, now, we take into consideration any two such shells.

Let $s_1, s_2, h_1, h_2, q_1, q_2$, be their specific resistances, their thermo-electric hardness, and their right sections, respectively.

Let $s_{12}, h_{12}, q_{12}=q_1+q_2$, be the specific resistance, thermo-electric hardness, and right sections, respectively, of a single shell, which is capable galvanically and thermo-electrically to replace the two original shells (they are actually combined in multiple arc) in every respect. Then

$$h_{12}=\frac{h_2\frac{s_1}{q_1}+h_1\frac{s_2}{q_2}}{\frac{s_1}{q_1}+\frac{s_2}{q_2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and

$$s_{12}=\frac{\frac{s_1}{q_1}\frac{s_2}{q_2}}{\frac{s_1}{q_1}+\frac{s_2}{q_1}}q_{12} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

It therefore follows, in view of equation (1), that

$$h_{12}=\frac{n}{q_{12}}(q_1+q_2)\,s_{12}=n\,s_{12}$$

and in the same way generally

$$h_{1,2,3}\ .\ .\ .\ =\frac{n}{q_{1,2,3}\ .\ .\ .}\,\Sigma(q_k)\,s_{1,2,3}\ .\ .\ .\ =ns_{1,2,3}\ .\ .$$

That is, if the law $h=ns$ be true for the elementary (necessarily homo-

geneous) layers of the rod, then must it be true also for the rod taken as a whole, however complicated its structure may be, and whatever be the difference in the variation of the density of successive layers while annealing is in progress. The converse of this does not follow so readily.

The superficial layers of the steel, being the ones directly and immediately operated upon in sudden cooling, will probably be the ones experiencing greatest intensity of strain. It may be plausibly argued, therefore, that the effect of incipient annealing is confined to these, or at least that the said layers expand at a far more rapid rate than the rod as a whole contracts. The law $h=ns$ may therefore be considered to apply with good approximation, both in the case of volume expansion and of volume contraction.

We may account for the progressive errors encountered in the case of hard wires annealed at low temperatures ($<100°$) from two points of view: Either the elementary law $h=ns$ is not *rigidly* true throughout the phenomenal variation of density which the individual layers experience on tempering (probably from 7 to 10); in other words, $h=f(s)$ is no longer rigidly linear when we approach the enormous condensation near the surface, for instance. Or, the discrepancy may be due to the facts observed by Caron[32] that a hard-steel rod during the annealing contracts æolotropically; *i. e.*, not in like ratio both in the direction of its longitudinal and its radial axes. In such a case the law $h=ns$, conceded rigidly to hold good for isotropic strains, need no longer do so in the case in hand. This discussion will be advantageously resumed, in the light gained from further relevant data, in chapter III.[33]

## SOURCES OF ERROR.

The difference between the observed and the calculated results of thermo-electric hardness, as exhibited in the last paragraph, pertinently suggest an especial inquiry in regard to how far they are referable to errors of observation. This involves an examination into the possible descrepancies incident to the various methods of measurement used.

*Thermo-electric measurement.*—If we commence with the thermo-electric measurement we at once encounter a series of obvious sources of error which may be thus classified: Variation of the factor of reduction of the galvanometer, to be referred in part to fluctuations in the intensity of terrestrial magnetism, in part to the immediate influences due to changes of atmospheric temperature; the inconstancy of the electromotive force of the Daniell between the observations made for the determinations of the same; the effect of extraneous thermo-currents in

[32] Caron: Comptes rendus, LVI, p. 211, 1863.
[33] Chapter III, p. 88.

the galvanic connections; and, finally, the difficulties surrounding an accurate measurement of the temperatures of the thermo-electric junctions, especially when they are high. The first two of these may be satisfactorily avoided by frequent repetitions of a series of systematic and corroborative measurements. The devices[34] by which we endeavored to eliminate the third have already been fully described; nevertheless the distortion due to this cause is not thoroughly eliminable, and its effect will be most apparent in the case of small values of thermo-electric force. Steel wires lying very near pure silver in the thermo-electric scale are therefore apt to be seriously influenced. Conformably herewith, the column of "differences" in the foregoing table (34) shows large values when $y'$ is approximately zero. But there is another reason for these relatively large discrepancies, which deserves mention as being even of more importance than the one just referred to. The thermo-electromotive force is expressed by the aid of two constants, thus—

$$e=a\,(T-t)+b\,(T-t^2)$$

whence it follows that the accuracy of the constant $a$, resulting from the calculation, is conditioned to some extent by the accuracy of $b$; for, although the latter is usually small relatively to the former, it enters the equation

$$e=[a+b\,(T+t)]\,(T-t)$$

as a co-efficient of the sum of the temperatures $T$ and $t$. Now, an accurate measurement of $b$ presupposes a large range of variation of the difference of temperatures $T$ and $t$; and it is just here that in the case of glass-hard rods we encounter an unavoidable difficulty. Large values of $T$ are inadmissible, because they change the temper of the exposed junction of the rod. It is equally inexpedient to cool $t$ below zero. At least our attempts in this direction served only to convince us that the errors encountered in consequence of insufficient constancy of $t$ more than counterbalance the advantages gained, to say nothing of annoyances of a practical kind. An inspection of some of the earlier tables will show that wherever the value of $a$ is larger or smaller than was with good reason to be anticipated, this discrepancy is compensated by a similar error of $b$. Indeed the calculations from which the constants of the 90 series of experiments given above were derived, clearly show that a number of observations greater than four for each value of $a$ is indispensable for an advantageous application of the method of least squares. This did not urgently appeal to us until the measurements were well in progress, and we were equally undesirous both of changing the routine adopted and of encountering additional labor in the calculations. Four observations, however, will not suffice where an accuracy of $a$ within one per cent. is demanded. We also observed that

[34] Cf. pp. 34–35.

the correlative values of $a$ and $b$ were materially different, according as the equation

$$y = ax + bxu$$

or

$$\frac{y}{x} = a + bu$$

was assumed for the application of the method of least squares.

*Resistance measurement.*—The values for specific resistance are liable to two sources of error. The first of these, which is due to variations of temperature, the results contained in Chapter 1 have enabled us largely to eliminate. The second error is of a more serious kind, and embraces the difficulties encountered in endeavoring to obtain values for the sections of (thin) rods. As the average thickness of our wires was only about 0.05 centimeter, it would have been necessary to measure the mean diameter to $\frac{1}{1000}$ centimeter in order to arrive at a mean section correct to within one per cent. This is not feasible, except with extreme precautions, either by the use of microscopic or gravimetric methods. In the case of thinner wires the difficulty is proportionately increased. Such errors as are due to imperfections of contact at the places of insertion of steel wires, etc., have been already touched upon.[35] They were wholly avoided eventually by a change of method.

*Other errors.*—In addition to the sources of errors just mentioned, such as are more intrinsically connected with the subject discussed, deserve consideration. It has been stated that the inference is warranted that the rods used were not quite identical as regards chemical composition, and that the electrical behavior of these, though alike in kind, may differ in degree.

## CONCLUDING REMARKS.

A brief review of the general tenor of the results discussed in the above, in so far as they have a bearing on certain important consequences which we desire now to touch upon, will be in place here. We purposely avoid all remote theoretical speculations and confine ourselves to inferences immediately deducible from the facts.

*Tempering.*—The physics of the process of tempering have thus far been but slightly understood; and it is therefore to the new light which the present chapter throws upon the essential features and results of this operation that we desire first to advert. Only cursory attention[36] has hitherto been given to the phenomenal difference between

[35] Cf. pp. 37–38.

[36] In certain thermo-electric measurements incidentally made by Joule (Phil. Trans., 1859, I, pp. 95–97). The results for variation of specific resistance of all earlier observers (Mousson, Chwolson) are erroneously small.

the extremes of mechanical state: the glass hard and the soft. The largest thermo-electric interval observed in the present work is 10.17—(−2.60)=12.8; and the maximum ratio of the respective values of specific resistance, $\frac{1.5}{0.5}=3.0$. It is this enormous range of variation of the electrical properties, together with the facility with which *absolute* data dependent merely on qualities essentially inherent in steel are obtainable, that would seem emphatically to recommend the scale of hardness here introduced to the attention of physicists. Furthermore, the method of annealing adopted enables the observer to carry the temper from any given initial state to any desirable final state within the range of possible variation in a safe and systematic way. Of the two factors which condition the degree of hardness reached—the temperature of the annealing bath and the time of exposure of the hard steel rod—the latter if sufficiently prolonged is particularly effective for very small values of the former. If annealing be continued through infinite time, the ultimate states (measured as thermo-electric hardness), would appear to decrease continuously as the temperature increases, though there is reason to predict the existence of a minimum between 400° and 600°. We had commenced a special investigation of this functionality, but the work was forcibly interrupted. It is still to be noted that the maximum annealing effect of a temperature $t'$ is independent of the possibly pre-existing effects of a temperature $t$, and is not in any way influenced by subsequent applications of the latter, provided $t'>t$.

*Scheme for magnetic and other allied researches.*—The results above detailed open up a large field for further research in directions differing from those of the present chapter. Indeed, wherever we have to deal with those properties which depend essentially on the hardness of steel, the experiments discussed in the above formally prescribe, as it were, a method of procedure at once expedient and safe.

From a physical point of view, steel possesses a special and peculiar interest in virtue of its pronounced magnetic properties. The importance of the influence of hardness on the intensity of permanent magnetization has long been known. But the confusion and discordance in the results of all observers bear witness to the difficulties encountered, not only from the vagueness which attaches to the term steel, but principally out of the want of a method by which identical mechanical states can be rigidly defined. As a consequence the data of many laborious researches do not readily admit of direct comparison, and are therefore nearly valueless. Indeed, we may add that even in the case of one and the same type of steel each rod must be regarded as an individual.

It follows, therefore, that a plan of research in which a given steel rod is carried, by annealing, from an initial hard to a final soft state, through all intermediate states, is alone adapted to the class of experiments under discussion. And here again the peculiar mechanical condition

which we have above characterized as the limit of hardness for a given temperature of the annealing bath will appear saliently important. The reasons for this preference are obvious. We have in hand the highest of the inferior states of hardness permanently unaffected by the given circumstances of exposure; the maximum of *permanent* hardness, in other words. We are justified in ascribing to it greater uniformity of temper and greater definiteness of internal structure than is possessed by steel tempered in any other way whatsoever. Thus it will be possible, independently of the degree of carburation of steel, or of its chemical composition in general, independently, moreover, of the geometrical figure of a given sample, to investigate the magnetic variation due to the the change of a single variable hardness alone. With this as a point of departure, the inquiry leads to the effect of form or dimensions, and ultimately to that of carburation.

## ADDENDUM: ON A SIMPLE METHOD FOR THE GALVANIC CALIBRATION OF A WIRE.

The methods in vogue for the calibration of an electrical measuring wire, one, for instance, to be used in the Wheatstone-Kirchhoff bridge, are without doubt inconvenient in so far as they presuppose a set of resistance coils of known simple ratios. In other words, they call for the preliminary work of comparing with great care the said auxiliary coils. The accuracy of the result immediately sought is thus dependent on the accuracy of the earlier measurement, and the anticipative caliber errors of the wire are obscured by the errors possible in the accepted ratios of the coils themselves—particularly so where, as is generally the case, the discrepancies primarily in question are small. In view of the importance of the very accurate and convenient method of determining resistances by means of the sliding-contact bridge, the endeavor to overcome the obstacles mentioned as completely as possible is therefore at once justifiable. A method moreover which can accomplish this will be all the more acceptable in proportion as the auxiliary devices to be adopted are simple and readily available. We believe the following plan partakes of these advantages.

The method now to be described, and which we have profitably employed in determining the sectional errors of an electrical measuring wire, is a complete analogon of the procedure usually employed for the calibration of thermometers. The immediate principles and the point of departure are the same as those utilized in the well-known Matthiessen-Hockin method of resistance measurement. In the annexed figure, in which the ordinary bridge adjustment is diagrammatically given, let $A\,N\,B$ and $A\,M\,B$ be the two branches terminating at $A$ and $B$, where

$A\ M\ B$ is the wire to be calibrated, $A\ N\ B$ a series of resistances, whose sum in any given case remains constant.

Now, if $M_1$ and $N_1$, $M_2$ and $N_2$ are, respectively, pairs of points of like

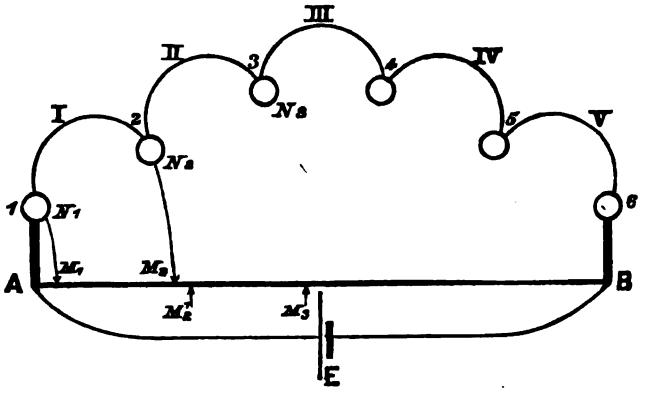



FIG. 12.—Disposition of apparatus for calibration.

potential, and if the resistance of $N_1\ N_2$ be $Y$, and the length of the part $M_1\ M_2$ be $x$, then

$$Y = C\,x,$$

where $C$ is a constant (sensitiveness) dependent only on the sum of the resistances $A\ N\ B$. Indeed, if $W$ be this sum, and $L$ the total length of wire $A\ M\ B$, then

$$W = C\,L.$$

Furthermore, let the interval of calibration $a$ be so chosen that $\frac{L}{a} = n$, where $n$ is an integer.

Suppose, now, that $n$ approximately equal resistances are either specially constructed or at the observer's disposal. In our case a number of tenths of Siemens mercury units, which had been made for the purpose of serving as normals for resistance comparisons, were available. But in general it is wholly sufficient to select a german silver wire of appropriate length and thickness, to cut it into $n$ approximately equal parts, and then to solder the ends of each of these to terminals of thick copper, the free ends of which, in their turn, are to be amalgamated so that mercury contacts may be used at $N_1, N_2 \ldots, N_6 \ldots$ throughout. Further knowledge of the resistance ratio of these auxiliary wires is quite unnecessary.

These $n$ approximately equal resistances $I, II, III \ldots$ are joined in series by mercury cups, as shown in the diagram. To have a concrete case, let $n=5$, for which assumption the figure applies. The extreme points $A$ and $B$ of the measuring wire are connected by pieces of thick copper with the extreme mercury cups. The calibration is then effected as follows:

One of the prolonged terminals of a sensitive galvanoscope is con-

nected consecutively with the points $N_1$, $N_2$; and by means of the other terminal the corresponding positions of the sliding contact on the wire $A\,M\,B$, viz, $M_1$, $M_2$, respectively, determined.

Then *I* and *II* are exchanged, so that the resistance wire *I* now occupies the former position of *II*, and *vice versa;* and while one of the terminals of the galvanoscope is connected consecutively with the mercury cups $N_2$ and $N_3$, the other enables us to determine the corresponding positions of the sliding contact on the wire $A\,M\,B$, viz, $M_2'$ and $M_3$, respectively.

After this, *I* and *III* are exchanged. The contacts of one galvanoscope terminal at $N_3$ and $N_4$ fix the positions of the sliding contact at $M_3'$ and $M_4$, respectively. And so on until *I* has passed consecutively from its original first position to the final portion among the whole series of resistances $A\,N\,B$. In this way we obtain on the wire $A\,M\,B$ the nearly consecutive parts $M_1\,M_2$, $M_2'\,M_3$, $M_3'\,M_4$ . . . of like resistance.

Herewith it is obvious that this method of galvanic calibration is strikingly analogous to the method adopted in thermometer calibration. In the latter case a mercury thread of a given constant convenient volume and the approximate length $a=\frac{100}{n}$ is moved from place to place in the tube, and its length for each of these positions determined in terms of the thermometer scale—lengths which under assumption of a constancy of caliber would be proportional to the volume of the thread, and hence identical. In the former electrical measurement, a wire of constant resistance is moved from place to place, and its value, as it were, determined in terms of lengths of the measuring wire, which again under conditions of constant sections would be proportional to the said moving resistance, and therefore identical. In both cases, finally, the sectional error of the tube or wire is shown by the discrepancies or differences in the observed lengths of mercury thread or wire-part, respectively. In thermometry, the two fixed points, with reference to which the calibration is completed, are the freezing and the boiling points of water. On the bridge the corresponding points coincide with the extremities *A* and *B* of the wire.

Let $a_1, a_2, a_3, \ldots$ be the equivalent wire parts of $A\,M\,B$, determined by direct observation. Then will the mean length of these, which under assumption of a mean section of the calibrated wire corresponds to the calibration resistance, be

$$\frac{a_1+a_2+a_3+\ .\ .\ .\ .\ a_n}{n}$$

But as $a_1$, $a_2$, $a_3$ differ but slightly from the calibration interval $a=\frac{L}{n}$, it is practically convenient not to introduce into the calculation the

whole lengths $a_1 \ . \ . \ . \ a_n$, but merely their (positive or negative) differences from $a$. Therefore let

$$a_1 = a + \delta_1; \ a_2 = a + \delta_2 \ . \ . \ . \ a_n = a + \delta_n$$

and similarly

$$\frac{a_1 + a_2 + a_3 + \ . \ . \ . \ a_n}{n} = a + \alpha.$$

Then, more simply, there follows

$$\alpha = \frac{\delta_1 + \delta_2 + \delta_3 + \ . \ . \ . \ \delta_n}{n}$$

and therefore for the table of calibration of the wire,

| | |
|---|---|
| from 0 to $a$ . . . . . | $\alpha - \delta_1$ |
| from $a$ to $2a$ . . . . . | $\alpha - \delta_2$ |
| from $2a$ to $3a$ . . . . . | $\alpha - \delta_3$, etc. |

Therefore by summation:

At $a$, correction $= \alpha - \delta_1$
At $2a$, correction $= 2\alpha - \delta_1 - \delta_2$
At $3a$, correction $= 3\alpha - \delta_1 - \delta_2 - \delta_3$, etc.

As the main feature of the present method, we desire again to advert to the simple means by which the calibration is effected. The only error to be guarded against is the possibility of variation of temperature during the course of the consecutive adjustments of the calibration resistance. But the work can be accomplished rapidly—all the more as the approximate positions of $M$ are readily predeterminable with considerable accuracy. If a fairly sensitive galvanoscope be employed the errors of adjustment are of the same order as the errors of observation. In case of our special bridge $2\frac{1}{2}$ meters long, very ordinary means enabled us to secure an accuracy of adjustment within 0.1 millimeter.

By means of the principle here enunciated any of the other methods of thermometer-calibration would be equally applicable. The convenient one given, however, is sufficient for all practical purposes.

## CHAPTER III.

### THE NATURE OF THE PHENOMENON OF TEMPER AS OBSERVED IN STEEL DISCUSSED FROM AN ELECTRICAL STANDPOINT—PARTICULARLY IN REFERENCE TO THE ANALOGOUS BEHAVIOR OF MALLEABLE CAST-IRON AND OF ALLOYS OF SILVER.

### INTRODUCTION.

*General inferences deducible from the cast-irons.*—If we abstract from grossly impure material, details and ulterior complications, the different kinds of cast-iron may be conveniently classed with reference to two well-known types—the gray cast-iron and the white cast-iron—which are thoroughly distinct and well marked, as regards both their chemical and their mechanical properties. Reasons for this classification, it is believed, are not far to seek, and they are such as depend on the manner in which the carbon contained is combined with the iron. White cast-iron is known to contain carbon in the chemically combined state only. In gray cast-iron, however, the uncombined or mechanically admixed forms of carbon are present in much the greater proportion. Furthermore, it is known that a given specimen of molten iron may be changed into either the gray or the white type, respectively, according as the cooling, after casting, is permitted to take place very gradually or very rapidly.[37] In this respect an experiment of Karsten's[38] is peculiarly instructive. Karsten poured molten iron into a thick iron mold. The outer layers of the cold mass, which in this way had cooled at a comparatively rapid rate, were found to contain combined carbon only. In the inner and axial layers, however, where cooling took place gradually, only about one-sixth of the total carbon occurred in the combined form.[39] Suppose we compare the process of fast and slow cooling in the case of cast iron, with sudden chilling and very gradual cooling in case of steel, respectively; suppose, furthermore, we contrast the very high degree of hardness possessed both by white cast iron and chilled steel with the readiness with which gray cast-iron and slowly

[37] The remarks here made present the facts under consideration only in a brief and introductory way. For full and exhaustive discussions the reader is referred to Percy-Wedding, Eisenhüttenkunde, Bd. II of the German Percy, pp. 130–186, Braunschweig, 1864. Cf. particularly critical remarks, pp. 165–167.

[38] Karsten: Eisenhüttenkunde, Bd. I, 3 Aufl., 1841, p. 581 ff.

[39] The results of Karsten's analysis are these:

Before melting (iron homogenous): C combined, 0.8 per cent.; C uncombined, 3.2 per cent.

After melting (outer layers): C combined, 5.1 per cent.; C uncombined, 0.0 per cent. Inner layers: C combined, 0.6 per cent.; C uncombined, 3.2 per cent.

cooled or thoroughly annealed steel yield even to an ordinary file; then the inference is apparently unavoidable that the hardness which may be imparted to steel by a process of tempering is to be referred to the transfer of carbon from the uncombined to the combined state.[40]

*Data corroborating this analogy.*—If, however, what may be called the chemical method of accounting for the hardness in steel were alone dependent on analogies of the kind just sketched, we would not be inclined to accept it immediately and with full confidence. In glass-hard steel we encounter strains of a peculiar character and of enormous intensity. It is upon such observations that a purely physical explanation of the hardness in question might be based—an explanation much better adapted for the prediction of certain physical phenomena to be mentioned below than the chemical view under consideration. At the very outset we come upon difficulties. Suppose, for instance, we attempt to draw further inferences from Karsten's experiment. We find that the glass-hard external layers of his cylinder, consisting wholly of white cast iron, possess the specific gravity 7.55, whereas the specific gravity of the gray nucleus was only 7.18. The effect of sudden chilling in case of steel,[41] however, is a very marked diminution of density of the rod, as a whole. Even if we pursue our inference further, and endeavor to compare the external and internal layers of a glass-hard steel rod with the corresponding parts of Karsten's chilled iron cylinder, respectively, we fail to arrive at satisfactory results; for the density of the external layer of a steel bar (about 10) is incommensurately large when compared with the above datum for white cast-iron. The chemical explanation, however, at once becomes of incontestible importance when it is found that in addition to the given analogies we have in hand a number of data which go to prove that carbon exists differently, as regards its mode of occurrence, in hard and in soft steel. The data are derived from the chemical behavior of soft and hard steel toward acids. In this place the extensive experiments of Caron[42] need alone be mentioned. The results of this observer with steel in the commercial, the hammered, and the glass-hard states, respectively, furnish striking evidence of the fact that the mode of occurrence of carbon in

[40] Cf. Karsten: Karsten u. v. Dechen's Archiv., XXV, p. 223, 1853. Cf., also, p. 103 of the present paper.

[41] Karsten: op. cit., Bd. I, p. 193–4, experiments of Hausmann and Karsten. Cf. also ibid., p. 184, ff. For a table for Swedish Bessemer steel, see "Steel, its history, etc.," J. S. Jeans, Sec. Br. Iron and Steel Inst., London, Spon, 1880; Cf. ibid., p. 612–615. On the mean specific gravity of iron-carburets, cf. Karsten, op. cit., p. 183.

[42] Caron: Comptes rend., LVI, p. 43, 1863. The residues in the cases referred to, viz., 1.62 per cent., 1.24 per cent., 0.24 per cent., were found to contain 0.83 per cent., 0.56 per cent., 0.00 per cent. of carbon, respectively. The following remark of Caron's moreover, is of especial importance here: "Ainsi de l'acier trempé ayant été recuit pendant un temps variant entre quelques heures et plusiers jours a donné après dissolution des quantités de carbon libre qui ont augmenté en même temps que la durée et l'intensité des chauffes." pp. 45–46.

soft steel is thoroughly different from the chemical condition of this element in hard steel. In so far, then, as it is necessary to associate with this difference of chemical state of the carbon in steel some corresponding difference in the mechanical properties of this material, the validity of the chemical explanation of tempering may be said to have received its first important vindication.

*Results at variance with chemical hypotheses.*—Of late many facts have been adduced by various observers and in different ways against the hypothesis that the union of carbon and iron is ever of a thoroughly chemical character. Singularly clear in this respect are the views of Matthiessen,[43] who supposes that iron-carburets are to be regarded either as solidified solutions of carbon in iron, or as solutions containing carbon mechanically admixed. To these new opinions Matthiessen is led by a study of the electrical conductivity of these materials. With this general hypothesis the results of the calorimetric researches of Troost and Hautefeuille[44] are in strict accordance. These observers find that not only carbon but silicon show such thermo-chemical relations toward iron as call for a classification of iron-carburets with the category of solutions. Forquignon,[45] finally, who has lately been occupied with similar researches, gives to this view his unqualified assent.

*Ulterior consequences of the chemical theory in case of steel.*—In connection with our researches on the hardness of steel a careful consideration of the subject in hand appeared necessary. Our attention was not, however, attracted to the questions just developed, viz., whether a chemical or mechanical explanation for the mode of occurrence of carbon in steel is more in coincidence with facts. The subject-matter of importance to us is sketched in all its essential points in the earlier sections. It is our endeavor to investigate whether a given change in the state of hardness of a steel rod is to be ascribed to a corresponding change in the mode of occurrence of the carbon in this material, or whether the presence of carbon imparts to iron certain distinct and unique properties ("steel") in such a way that the whole series of the phenomena observed in tempered steel are to be regarded as purely mechanical in their character. It may be observed that the first manner of explanation does not necessarily conflict with the second. Both chemical and mechanical phenomena may coexist. But it is best in this place to hold the two hypotheses strictly apart. This is readily possible, because the different states of hardness obtainable from a glass-hard steel rod by annealing are all reached, practically, when the temperature of the annealing bath is still below 350°, a temperature insufficiently high for the conversion of uncombined into combined carbon.

[43] Matthiessen: Rep. Br. Assoc. Adv. Sc., 1866, p. 15.

[44] Troost and Hautefeuille: Ann. de ch. et de phys. (5), IX, 1876, p. 70.

[45] Forquignon: Ann. de ch. et de phys. (5), XXIII, 1881, pp. 531–536.

Suppose now that we abstract from physical considerations altogether for the time being, and endeavor to obtain from the older and more thoroughly investigated chemical hypothesis an explanation for the details of the phenomena of annealing discussed in an earlier chapter.[46] If sudden chilling is accompanied by chemical combination of the carbon in steel, then must the operation of annealing, which reverses the effects of the former, enable us to reconvert combined carbon into its original uncombined state.[47] But we have shown that for each temperature of exposure during the annealing of a glass-hard rod there exists a distinct degree of hardness, *cæteris paribus*, characteristic of the temperature in question alone. It follows, therefore, that to each temperature of the annealing bath there must correspond a certain fixed ratio of combined to uncombined carbon, the time of exposure being indefinite. From the known behavior of steel in different states of temper, moreover, combined carbon, must be looked upon as electrically active, uncombined carbon as electrically neutral. Thus we have it in our power, with the aid of the simple process of sudden chilling combined with subsequent annealing, in so far as in this way, within certain limits, any given amount of an electrically active ingredient may be converted into an electrically passive form, to reach the same results which, in the case of alloys, for instance, are obtainable only by melting the two component metals together in a ratio which may be called for. We said "within certain limits"; the superior limit here meant, is the total amount of carbon present in the given type of (normal) steel; the inferior limit, the small amount of combined carbon which even after most prolonged and gradual cooling cannot be made to appear in the uncombined state. With this chemical interpretation, finally, the remarkable linear relation between the thermo-electric constant and the specific resistance of steel passing continuously from the glass-hard to the soft state would at once appear to possess broader significance than that of being a special peculiarity of steel.

These are the reflections which induced us to undertake the present investigation. We were in hopes, moreover, that the results would prove of such a character as to enable us to derive inferences from them on the chemical nature of steel. At all events, the subject, considered from the standpoint of its own merits, is not undeserving of detailed attention. The number of data in hand on the relation in question is almost insignificant.

[46] Strouhal u. Barus: Wied. Ann., XI, p. 962, 963, 1880. Chapter II, pp. 43 et seq.

[47] Caron: l. c., pp. 45, 46. Unfortunately we have not been able to find any data relative to the effect of ordinary annealing (exposures below 400°) on the mode of occurrence of carbon in steel.

## EXPERIMENTS WITH ALLOYS.

*Earlier results inadequate.*—The literature on the electrical conductivity of alloys is very voluminous, but the exhaustive researches of Matthiessen[48] contain all the essential data. At least, little has been developed that has a bearing on the present paper since the date of Matthiessen's main research.[49] From the tables and graphical constructions there given, the conductivity of a large number of alloys can be at once deduced when the proportion in which the ingredients of the alloy are mixed is known. Similar remarks by no means, however, apply to our knowledge of the thermo-electric properties of alloys. Qualitative results are not lacking. Available quantitative data are, however, very rare.[50] Pairs of values of both the electrical conductivity and the thermo-electric power of alloys are only to be found in isolated examples, if at all. At least we were not able to obtain other data than a few measurements incidentally made by Sundell.[51]

Matthiessen's numerous results made a special determination of data on the relation between percentage composition and either of the electrical constants superfluous. Such measurements presuppose chemical analysis, which could not have been made without unduly sacrificing the greater part of our wires and material. By weighing out the ingredients, and careful fusion, we were able to obtain from Matthiessen's tables a satisfactory corroboration of our results.

*Material, fusion, preparation, etc.*—The general plan adopted in our researches with alloys was such as would correspond to a progressive increase in the state of hardness of steel from the soft or thoroughly annealed to the glass-hard condition, premising the views discussed in the last section. We commenced with pure silver, to which more and more of a second metal was successively added, until finally mechanical difficulties were encountered such as prevented a drawing of the alloy to wire. In case of silver-gold alloys, a complete series, commencing with silver and ending with gold, were obtainable. The alloys examined are those of silver with gold, platinum, copper, and zinc. Silver and gold were obtained pure from the mint at Frankfort; platinum, from the shops of Heraeus in Hanau. The copper was deposited electrolytically from a copper-sulphate solution. In making the alloys we proceeded thus: A weighed amount of silver having been well fused on a bone-ash cupel by the aid of a blast-lamp, the proper quantity of the second metal was added to it. Solution is usually immediate. Having mixed

[48] Matthiessen: Pogg. Ann., CX, pp. 190–221, 1860.

[49] Matthiessen and Holzmann: Pogg. Ann., CX, pp. 222–234, 1860; Rep. Br. Assoc. Adv. Sc., 1863, p. 37.

[50] We may, perhaps, mention Joule: Phil. Trans., 1859, I, p. 96 (Bi, Sb); Sundell: Pogg. Ann., CXLIX, 1873 (Bi, Sb, Sn).

[51] Sundell: *Ibid.*, pp. 154-170.

two component metals as thoroughly as possible by chasing the bule over the surface of the cupel, the flame was withdrawn and a ss bell-jar filled with hydrogen (the gas being continually resupplied ough an aperture in the neck of the jar), quickly placed over it. ydation, as well as absorption of oxygen by the melted globule, was is avoided, the button cooling in an atmosphere of hydrogen. Only the case of silver-copper alloys is this simple process to be regarded sufficient for the attainment of very accurate results.[52] But the dis-epancies thus introduced into our work, and which are due to absorp-on of oxygen by copper, are quite insignificant. Of this fact a mparison of Matthiessen and Holzmann's data with our own has fully nvinced us. On the other hand, the variation of thermo-electric ower and conductivity of alloys of silver and copper takes place within mits so nearly coincident that the general character of the diagram hich we will endeavor to construct below is in nowise distorted.

The buttons[53] were hammered and drawn down to wires of appropriate liameter. These were then annealed at high red heat in a current of ydrogen by the aid of a dynamo-electric machine. We were able to regulate the intensity of current, and with it the glow, by introducing into the circuit a solution of copper-sulphate, in which the copper electrodes were kept at suitable distances apart. Accidental fusion of the hot wires was thus not to be apprehended. After this annealing they appeared soft and flexible. Only the middle parts of the wires, over the whole length of which the glow had been uniform, and which, for other reasons, were apt to be homogeneous, were reserved for the measurements.

*Method of thermo-electric measurement.—Results.*—The methods of measurement of thermo-electric power and specific resistance are identical with those employed in our earlier researches.[54] The former is throughout referred to pure silver as a datum, *i. e.*, denotes the power of a thermo-element, one part of which is always silver; the other, however, the given alloy. Junctions were carefully soldered. The composition of all alloys is given in volume per cents, the data expressing the volume of the metal alloyed to silver in 100 volumes of alloy. It has been stated that these numbers are only approximate, since during fusion the two metals will hardly have been volatilized in like ratios.

With these remarks the following tables (35–39) will be readily intelligible. The thermo-electric constants $a$ and $b$ are calculated on the basis of Avenarius'[55] formula, $e=a\ (T-t)+b\ (T^2-t^2)$, from six corre-

[52] Cf. Matthiessen u. Holzmann: *l. c.*, pp. 222–224.

[53] It would have been desirable to operate with larger quantities of metal, but these were not at our disposal.

[54] See Chapter II, p. 31 *et seq.*

[55] Avenarius: Pogg. Ann., CXLIX, p. 374, 1873. $e$ is the electro-motive force for the temperatures $T$ and $t$ of the junctions of the given thermo-element whose constants are $a$ and $b$.

sponding values of $e$, $T$, $t$, for each alloy, by the method of least squares. The measurements were originally made in Weber-Siemens' units, and then reduced to current values by the relation ohm = 1.06 Siemens.

TABLE 35.—*Thermo-electric power of alloys.*

| Alloy. | Vol. P. ct. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|---|
| | | C. | C. | *microvolt.* | *microvolt.* | | | |
| Silver-platinum | 2 | 16.5 | 85.6 | −308.6 | −308.8 | 0.2 | −3.95 | −0.[illegible] |
| | | 16.6 | 75.7 | −261.3 | −261.1 | −0.2 | | |
| | | 16.7 | 64.1 | −206.7 | −206.7 | 0.0 | | |
| | | 16.7 | 53.6 | −159.1 | −159.1 | 0.0 | | |
| | | 16.8 | 43.1 | −111.7 | −111.9 | 0.2 | | |
| | | 16.8 | 36.3 | − 82.4 | − 82.3 | −0.1 | | |
| Do | 5 | 15.8 | 78.6 | −413.0 | −412.5 | −0.5 | −5.72 | −0.[illegible] |
| | | 15.9 | 69.3 | −346.3 | −346.4 | 0.1 | | |
| | | 15.9 | 60.9 | −288.2 | −288.5 | 0.3 | | |
| | | 16.0 | 52.3 | −230.1 | −230.1 | 0.0 | | |
| | | 16.1 | 45.8 | −186.4 | −186.5 | 0.1 | | |
| | | 16.1 | 37.5 | −132.9 | −132.7 | −0.2 | | |
| Do | 10 | 17.1 | 90.6 | −604.4 | −603.4 | −1.0 | −6.77 | −0.[illegible] |
| | | 17.1 | 79.1 | −498.3 | −499.6 | 1.3 | | |
| | | 17.1 | 68.3 | −405.2 | −405.0 | −0.2 | | |
| | | 17.1 | 55.4 | −296.8 | −296.4 | −0.4 | | |
| | | 17.1 | 45.2 | −213.8 | −213.7 | −0.1 | | |
| | | 17.2 | 35.2 | −134.4 | −134.6 | 0.2 | | |
| Do | 16 | 16.1 | 90.2 | −710.6 | −709.4 | −1.2 | −7.90 | −0.[illegible] |
| | | 16.1 | 74.0 | −539.7 | −539.5 | −0.2 | | |
| | | 16.2 | 62.9 | −425.6 | −427.1 | 1.5 | | |
| | | 16.2 | 52.4 | −324.9 | −324.9 | 0.0 | | |
| | | 16.3 | 43.4 | −230.4 | −239.5 | 0.1 | | |
| | | 16.3 | 36.2 | −174.0 | −173.6 | −0.4 | | |

TABLE 36.—*Thermo-electric power of alloys.*

| Alloy. | Vol. P. ct. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|---|
| | | C. | C. | *microvolt.* | *microvolt.* | | | |
| Silver-gold | 5 | 15.5 | 85.1 | −132.9 | −132.9 | 0.0 | −1.77 | −0.0014 |
| | | 15.5 | 75.5 | −114.1 | −113.7 | −0.4 | | |
| | | 15.4 | 68.3 | − 99.1 | − 99.8 | 0.7 | | |
| | | 15.4 | 62.0 | − 87.8 | − 87.5 | −0.3 | | |
| | | 15.4 | 50.6 | − 65.5 | − 65.5 | −0.0 | | |
| | | 15.4 | 40.0 | − 45.4 | − 45.4 | −0.0 | | |
| Do | 15 | 15.4 | 89.5 | −209.2 | −209.5 | 0.3 | −2.38 | −0.0043 |
| | | 15.5 | 80.6 | −181.5 | −181.6 | 0.1 | | |
| | | 15.5 | 71.5 | −154.1 | −154.0 | −0.1 | | |
| | | 15.5 | 63.2 | −129.7 | −129.3 | −0.4 | | |
| | | 15.6 | 52.8 | − 99.3 | − 99.3 | 0.0 | | |
| | | 15.6 | 44.1 | − 74.8 | − 75.0 | 0.2 | | |
| Do | 25 | 15.7 | 90.2 | −227.0 | −227.0 | 0.0 | −2.54 | −0.[illegible] |
| | | 15.7 | 82.6 | −201.1 | −201.3 | 0.2 | | |
| | | 15.8 | 66.3 | −148.3 | −148.0 | −0.3 | | |
| | | 15.8 | 54.3 | −110.8 | −110.7 | −0.1 | | |
| | | 15.8 | 44.9 | − 82.5 | − 82.3 | −0.2 | | |
| | | 15.8 | 35.9 | − 55.9 | − 56.1 | 0.2 | | |
| Do | 35 | 13.9 | 88.3 | −223.6 | −223.7 | 0.1 | −2.61 | −0.0039 |
| | | 13.9 | 79.7 | −195.8 | −195.6 | −0.2 | | |
| | | 13.8 | 72.3 | −172.3 | −172.1 | −0.2 | | |
| | | 13.8 | 63.4 | −144.2 | −144.2 | 0.0 | | |
| | | 13.8 | 51.9 | −109.2 | −109.2 | 0.0 | | |
| | | 13.8 | 42.4 | − 80.9 | − 80.9 | 0.0 | | |

TABLE 37.—*Thermo-electric power of alloys.*

| Alloy. | Vol. P. ct. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|---|
| | | C. | C. | *microvolt.* | *microvolt.* | | | |
| Silver-gold | 50 | 15.0 | 87.1 | −202.3 | −202.6 | 0.3 | | |
| | | 15.0 | 78.2 | −175.4 | −175.2 | −0.2 | | |
| | | 14.7 | 65.6 | −138.7 | −138 5 | −0.2 | −2.39 | −0.0041 |
| | | 14.7 | 55.3 | −108.9 | −108.8 | −0.1 | | |
| | | 14.7 | 44.4 | − 78.2 | − 78.3 | 0.1 | | |
| | | 14.6 | 36.2 | − 50.1 | − 56.1 | 0.0 | | |
| Do | 75 | 14.1 | 86.1 | −151.5 | −154.4 | +2.9 | | |
| | | 14.1 | 77.5 | −135.1 | −133.5 | −1.6 | | |
| | | 14.1 | 68.0 | −111.9 | −111.4 | −0.5 | −1.71 | −0.0043 |
| | | 14.1 | 53.3 | − 79.3 | − 78.5 | −0.8 | | |
| | | 14.1 | 42.1 | − 55.8 | − 54.7 | −1.1 | | |
| | | 14.0 | 30.5 | − 30.7 | − 31.5 | 0.8 | | |
| Do | 90 | 17.3 | 91.0 | −116.0 | −117.7 | 1.7 | | |
| | | 17.3 | 80.2 | −100.8 | − 99.2 | −1.6 | | |
| | | 17.3 | 68.1 | − 79.3 | − 79.3 | 0.0 | −1.41 | −0.0017 |
| | | 17.3 | 57.0 | − 61.2 | − 61.0 | −0.2 | | |
| | | 17.4 | 45.7 | − 43.3 | − 43.1 | −0.2 | | |
| | | 17.4 | 34.6 | − 25.6 | − 25.8 | 0.2 | | |
| Gold | 100 | 15.3 | 89.1 | 19.3 | 19.3 | 0.0 | | |
| | | 15.4 | 80.7 | 17.0 | 17.2 | −0.2 | | |
| | | 15.5 | 70.9 | 14.8 | 14.7 | 0.1 | +0.275 | −0.00012 |
| | | 15.6 | 60 5 | 12.2 | 12.0 | 0.2 | | |
| | | 15.6 | 51.4 | 9.0 | 9.5 | 0.1 | | |
| | | 15.7 | 40.3 | 6.5 | 6.6 | −0.1 | | |

TABLE 38.—*Thermo-electric power of alloys.*

| Alloy. | Vol. P. ct. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|---|
| | | C. | C. | *microvolt.* | *microvolt.* | | | |
| Silver-copper | 2 | 14.6 | 83.7 | 0.3 | −0.6 | 0.9 | | |
| | | 14.6 | 77.7 | −1.2 | −0.6 | −0.6 | | |
| | | 14.6 | 68.2 | −0.7 | −0.6 | −0.1 | −0.023 | +0.0001 |
| | | 14.7 | 57.7 | −1.2 | −0.6 | −0.6 | | |
| | | 14.7 | 48.0 | −0.4 | −0.5 | 0.1 | | |
| | | 14.7 | 39.8 | −0.2 | −0.4 | 0.2 | | |
| Do | 5.6 | 13.7 | 89.5 | 1.6 | 1.0 | 0.6 | | |
| | | 13.7 | 80.4 | 1.2 | 0.9 | 0.3 | | |
| | | 13.8 | 72.8 | 0.6 | 0.9 | −0.3 | +0.021 | −0.0001 |
| | | 13.9 | 62.8 | −0.2 | 0.8 | −1.0 | | |
| | | 13.9 | 52.2 | 0.5 | 0.6 | −0.1 | | |
| | | 13.9 | 39.2 | 0.8 | 0.4 | 0.4 | | |
| Do | 15 | 14.3 | 84.3 | 4.0 | 3.6 | 0.4 | | |
| | | 14.3 | 75.5 | 2.6 | 3.0 | −0.4 | | |
| | | 14.3 | 65.3 | 2.5 | 2.4 | 0.1 | +0.041 | +0.0001 |
| | | 14.4 | 56.5 | 2.0 | 2.0 | 0.0 | | |
| | | 14.4 | 46.3 | 1.4 | 1.5 | −0.1 | | |
| | | 14.4 | 35.5 | 1.0 | 0.9 | 0.1 | | |
| Do | 50 | 14.3 | 83.3 | 11.6 | 11.8 | −0.2 | | |
| | | 14.3 | 72.9 | 9.0 | 9.1 | −0.1 | | |
| | | 14.4 | 63.4 | 7.1 | 7.1 | 0.0 | +0.045 | +0.0013 |
| | | 14.4 | 53.8 | 5.5 | 5.2 | 0.3 | | |
| | | 14.5 | 43.9 | 3.7 | 3.5 | 0.2 | | |
| | | 14.5 | 33.5 | 1.9 | 2.0 | −0.1 | | |
| Do | 75 | 16.2 | 86.9 | 8.7 | 9.2 | −0.5 | | |
| | | 16.3 | 74.0 | 6.8 | 6.7 | 0.1 | | |
| | | 16.3 | 64.8 | 5.2 | 5.2 | 0.0 | +0.020 | +0.0011 |
| | | 16.3 | 52.4 | 4.1 | 3.4 | 0.7 | | |
| | | 16.3 | 41.7 | 2.0 | 2.1 | −0.1 | | |
| | | 16.3 | 33.0 | 1.0 | 1.2 | −0.2 | | |

TABLE 39.—*Thermo-electric power of alloys.*

| Alloy. | Vol. P. ct. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|---|
| | | C. | C. | *microvolt.* | *microvolt.* | | | |
| Silver-zinc, with larger amount of zinc. | ..... | 15.5 | 87.0 | − 8.8 | − 8.6 | −0.2 | −0.024 | −0.0009 |
| | | 15.5 | 80.8 | − 8.0 | − 7.4 | −0.6 | | |
| | | 15.5 | 71.5 | − 4.9 | − 6.0 | +1.1 | | |
| | | 15.5 | 60.5 | − 4.3 | − 4.3 | 0.0 | | |
| | | 15.8 | 49.1 | − 3.2 | − 2.8 | −0.4 | | |
| | | 15.8 | 35.3 | − 1.3 | − 1.4 | +0.1 | | |
| Silver-zinc, with smaller amount of zinc. | ..... | 15.7 | 90.6 | −12.8 | −12.2 | −0.6 | −0.176 | +0.0001 |
| | | 15.7 | 81.0 | −11.1 | −10.7 | −0.4 | | |
| | | 15.8 | 72.2 | − 8.2 | − 9.4 | −1.2 | | |
| | | 15.8 | 58.3 | − 7.1 | − 7.1 | 0.0 | | |
| | | 15.8 | 48.0 | − 5.7 | − 5.4 | −0.3 | | |
| | | 15.9 | 40.7 | − 4.1 | − 4.2 | 0.1 | | |

*Specific resistance.*—The following table contains our data for the specific resistance of the same alloys to which the foregoing tables (35–39) refer. The first two columns need no explanation. Column third contains the resistance in ohms per meter of wire at the temperature in column fourth. Under $2\rho$ the diameter and under $s_t$ the specific resistance in micro-ohms at the temperature $t$ is given. The constant $a$, finally, whose signification is apparent from $s_t = s(1+\alpha t)$, enables us to calculate $s$, the specific resistance at zero centigrade, in micro-ohms.

It is to be remarked that all the measurements were originally made in Siemens' units (ohm=1.06 Siemens), and subsequently reduced. The temperature-coefficients used, $\alpha$, are obtained from the results of Matthiessen, C. Vogt, and v. Bose,[86] by calculating with the aid of their formulæ, $s_t$ for 100° and 0°, and then finding the mean coefficient ($\alpha$) between these limits. This is obviously permissible in our case.

TABLE 40.—*Electrical resistance of alloys.*

| Alloy (soft). | Vol. P. ct. | W 1 m | $t$ | $2\rho$ | $s_t \frac{cm}{cm^2}$ 0° | $a$ | $s \frac{cm}{cm^2}$ 0° |
|---|---|---|---|---|---|---|---|
| | | *ohms.* | C. | *cm.* | *microhm* | | *microhm* |
| Commercial silver | 100 | 0.2023 | 15.2 | 0.0319 | 1.619 | 0.00398 | 1.521 |
| Electrolytic silver | 100 | 0.1777 | 15.4 | 0.0337 | 1.589 | 0.00398 | 1.492 |
| Do | 100 | 0.1802 | 15.0 | 0.0335 | 1.546 | 0.00398 | 1.491 |
| Silver-platinum | 2 | 0.2431 | 11.3 | 0.0495 | 4.67 | 0.00130 | 4.60 |
| Do | 8 | 1.0802 | 15.2 | 0.0330 | 9.21 | 0.00072 | 9.11 |
| Do | 10 | 0.8054 | 11.0 | 0.0496 | 15.53 | 0.00043 | 15.46 |
| Do | 15 | 2.4027 | 15.2 | 0.0347 | 22.74 | 0.00033 | 22.63 |
| Silver-gold | 5 | 0.3887 | 15.5 | 0.0337 | 3.463 | 0.0025 | 3.329 |
| Do | 15 | 0.7483 | 15.6 | 0.0337 | 6.686 | 0.0012 | 6.561 |
| Do | 25 | 0.9886 | 15.7 | 0.0339 | 8.906 | 0.0008 | 8.799 |
| Do | 35 | 1.1350 | 15.1 | 0.0338 | 10.188 | 0.0007 | 10.079 |
| Do | 50 | 1.2098 | 15.4 | 0.0337 | 10.700 | 0.0007 | 10.595 |
| Do | 50 | 1.2190 | 15.2 | 0.0337 | 10.782 | 0.0007 | 10.667 |
| Do | 75 | 0.9177 | 16.2 | 0.0389 | 8.295 | 0.0009 | 8.174 |
| Do | 90 | 0.2772 | 11.2 | 0.0493 | 5.283 | 0.0016 | 5.188 |
| Gold | 100 | 0.1137 | 18.0 | 0.0495 | 2.193 | 0.00395 | 2.057 |
| Silver-copper | 2 | 0.2049 | 15.0 | 0.0338 | 1.844 | 0.0036 | 1.744 |
| Do | 5, 6 | 0.1036 | 11.0 | 0.0496 | 1.999 | 0.0034 | 1.894 |
| Do | 15 | 0.2292 | 16.8 | 0.0344 | 2.131 | 0.0033 | 2.016 |
| Do | 50 | 0.2370 | 16.2 | 0.0358 | 2.383 | 0.0029 | 2.271 |
| Do | 75 | 0.2314 | 16.7 | 0.0352 | 2.255 | 0.0031 | 2.138 |
| Silver-zinc | ..... | 0.1733 | 17.4 | 0.0500 | 3.403 | (0.0020) | (3.29) |
| Do | ..... | 0.2114 | 15.6 | 0.0500 | 4.151 | (0.0015) | (4.09) |

[86] Matthiessen u. v. Bose: Pogg. Ann., CIII, p. 412, 1858.

The following table (41) contains results of Matthiessen and others; $a$ and $b$ here are Matthiessen's constants for his relation between electrical conductivity and temperature. By means of these $\lambda$ and $\lambda'$, the electrical conductivity at 0° and 100°, respectively, were calculated. But, according to Matthiessen, $\lambda=100$ for hard silver; $\lambda=1.656$ for mercury, (0°). Hence

$$s_t=\frac{100}{\lambda_t}\,\frac{1.656}{1.06} \qquad \log s_t=2.19375-\log \lambda_t.$$

From these values of $s_t$ the constant $\alpha$ was then obtained, in the way already given, $s_t=s\,(1+\alpha t)$.

TABLE 41.—*Specific resistance of alloys of silver.*

[Results of Matthiessen (and C. Vogt).]

| Metal. | Hard or soft. | Vol. Per ct. | $\lambda$ at 0° Ag (h) =100 | $a$ | $b$ | $\lambda'$ at 100° Ag (h)=100 | $s\frac{cm}{cm^2}$ 0° | $s'\frac{cm}{cm^2}$ 100° | $\alpha$ 0°....100° |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *microhm.* | *microhm.* | |
| Silver | h | 100 | 100 | 0.38287 | 0.0009848 | 71.561 | 1.5623 | 2.1831 | 0.003974 |
| Do | s | 100 | 108.74 | 0.41570 | 0.0010624 | 77.794 | 1.4367 | 2.0062 | 0.003978 |
| Silver-platinum | h | 2.51 | 31.640 | 0.039863 | 0.00003642 | 23.068 | 4.938 | 5.566 | 0.001272 |
| Do | h | 5.05 | 18.031 | 0.013949 | 0.00001182 | 16.754 | 8.664 | 9.325 | 0.000763 |
| Do | h | 19.65 | 6.696 | 0.002214 | 0.00000139 | 6.489 | 23.981 | 24.075 | 0.000319 |
| Silver-gold | h | 19.86 | 21.684 | 0.019185 | 0.00001152 | 19.881 | 7.205 | 7.858 | 0.000906 |
| Do | h | 52.08 | 15.030 | 0.010120 | 0.00000370 | 14.055 | 10.394 | 11.115 | 0.000694 |
| Do | h | 79.86 | 21.335 | 0.023212 | 0.00001694 | 19.183 | 7.322 | 8.144 | 0.001123 |
| Do | s | 19.86 | 21.746 | 0.019753 | 0.00001895 | 19.910 | 7.184 | 7.847 | 0.000928 |
| Do | s | 52.08 | 15.060 | 0.010864 | 0.00000746 | 14.068 | 10.360 | 11.105 | 0.000719 |
| Do | s | 79.86 | 21.584 | 0.024589 | 0.00002506 | 19.881 | 7.238 | 8.061 | 0.001137 |
| Gold | h | 100 | 77.964 | 0.28648 | 0.0006582 | 55.898 | 2.0038 | 2.7948 | 0.003947 |
| Do | s | 100 | 79.327 | 0.29149 | 0.0006697 | 56.875 | 1.9694 | 2.7468 | 0.003947 |
| Silver-copper | h | 1.53 | 79.708 | 0.32868 | 0.0008965 | 53.905 | 1.960 | 2.904 | 0.004816 |
| Do | h | 8.25 | 80.284 | 0.22101 | 0.0003503 | 61.686 | 1.946 | 2.533 | 0.003017 |
| Do | h | 46.67 | 74.940 | 0.21011 | 0.0003961 | 57.890 | 2.085 | 2.699 | 0.002946 |
| Do | h | 77.64 | 69.811 | 0.21194 | 0.0004240 | 52.857 | 2.238 | 2.956 | 0.003208 |
| Do | h | 95.17 | 82.300 | 0.26758 | 0.0005717 | 61.259 | 1.898 | 2.550 | 0.003442 |
| Do | h | 98.35 | 89.544 | 0.30886 | 0.0007155 | 65.813 | 1.745 | 2.374 | 0.003606 |
| Copper | h | 100 | 99.947 | 0.38681 | 0.0009004 | 70.270 | 1.5631 | 2.2232 | 0.004223 |
| Do | s | 100 | 102.213 | 0.39557 | 0.0009208 | 71.864 | 1.5297 | 2.1739 | 0.004211 |

*Digest. Diagram.*—For the sake of perspicuity, the final results are tabulated again as follows.

TABLE 42.—*Corresponding values of the galvanic and thermo-electric constants.*

| Alloy. | Volume Per cent. | $s\frac{cm}{cm^2}$ 0° | $a\left(\frac{de}{d(T-t)}\right)_{(T+t)=0}$ |
|---|---|---|---|
| | | *microhm.* | |
| Silver-platinum | 0 | 1.49 | 0.00 |
| | 2 | 4.60 | —3.95 |
| | 5 | 9.11 | —5.72 |
| | 10 | 15.46 | —6.77 |
| | 15 | 22.63 | —7.90 |
| Commercial-platinum | 100 | *(8.67) | (0.33) |
| | | 13.44 | |
| Silver-copper | 0 | 1.49 | 0.000 |
| | 2 | 1.74 | —0.023 |
| | 5, 6 | 1.92 | 0.021 |
| | 15 | 2.02 | 0.041 |
| | 50 | 2.27 | 0.045 |
| | 75 | 2.14 | 0.020 |
| | 100 | 1.53 | (—0.114) |

* Applies for chemically pure metals. These values in parentheses are approximate, and are not immediately derived from observations.

TABLE 42.—*Corresponding values of the thermo-electric and galvanic constants*—Cont'd.

| Alloy. | Volume. Per cent. | $s\frac{cm}{cm^2}$ 0° | $\left(\frac{ds}{d(T-t)}\right)_{T=t=0}$ |
|---|---|---|---|
| | | microhm. | |
| Silver-gold | 0 | 1.49 | 0.00 |
| | 5 | 3.33 | −1.77 |
| | 15 | 6.56 | −2.36 |
| | 25 | 8.79 | −2.54 |
| | 35 | 10.08 | −2.61 |
| | 50 | 10.63 | −2.39 |
| | 75 | 8.17 | −1.71 |
| | 90 | 5.19 | −1.41 |
| | 100 | 2.04 | 0.27 |
| Silver-zinc | 0 | 1.49 | 0.000 |
| | ⩽ | (3.28) | −0.424 |
| | ⩾ | (4.06) | −0.176 |
| | 100 | 5.38 | (−0.092) |

The results contained in the last table (42) are given graphically in figure 13, specific resistance being represented as abscissa, thermo-elec-

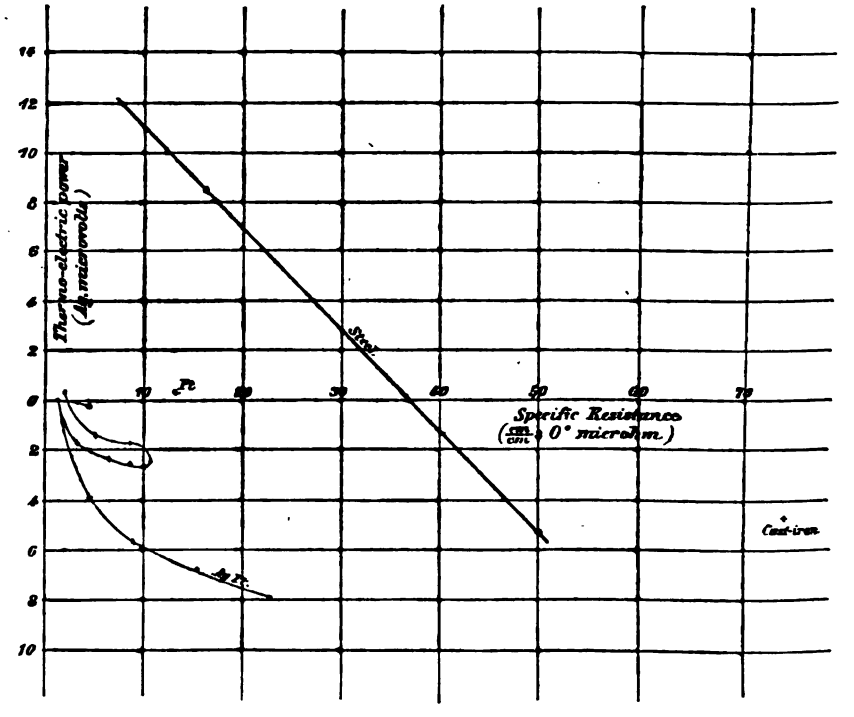



FIG. 13.—Specific resistance and thermo-electric constant: steel, silver-gold, silver-platinum, silver-zinc.

tric constant as ordinate. In order to facilitate comparison the linear relation which holds for steel (see chapter II, page 63) is also drawn,

and the interval of variation[57] of the constants in question indicated by two small circles near the ends of the line. All the constants are given in microhms and micro-volts, respectively, and the thermo-electric position is referred to silver.

*Discussion.*—A mere glance at the curves tells us that the relations under consideration are by no means of a simple character. Both properties, as exemplified by the thermo-electric constant and specific resistance, pass through maxima or minima, in such a way, however, that the said singular points do not coincide—*i. e.*, are not properties of one and the same wire as regards composition. Equally difficult is it to observe any perspicuous law for the direction of the line joining the extreme points (those corresponding to pure metals) of the curves. The very simple relations which obtain in case of steel would apparently lead to the anticipation of some result of this kind.

The given curves, however, apply only for fixed conditions of temperature; the galvanic constant $s$ only for the temperature $t=0$; the thermo-electric constant $a$ for the mean temperature $\frac{1}{2}(T+t)=0$. But the temperature-coefficient, both for thermo-electric power[58] as well as for specific resistance, varies in a marked degree as we pass from alloy to alloy. Hence it follows that for each temperature there exists a set of curves of the kind in question, characteristic of the said temperature. Change of temperature, therefore, involves a change in the curves both in figure and in position. It follows herefrom that a certain temperature must exist for which the figure of the curves is the simplest possible; our knowledge of the effects of temperature is, however, as yet insufficiently accurate to enable us to adduce further inferences. It is to be noticed that, at least as far as the above experimental matter is concerned, the magnitude of the given curves—*i. e.*, the range of variation of the involved electrical constants—is qualitatively in the order of the differences of the specific volumes of the metallic components of the respective alloys. The very large loop, obtained in the experiments with silver-platinum alloys, corresponds to the marked increase of hardness which these materials experience with increasing additions of platinum to silver. On the other hand, in the case of silver-gold and silver-copper alloys, a very great difference in the extent of the loop is apparent, unaccompanied by corresponding differences in the degrees of hardness[59] of the respective alloys. That the bulge in the different curves must be wholly to the right of the lines joining the extreme

[57] In later researches the superior limit was found to be even above 50.

[58] In reference to thermo-electric power we consider the quantity $2b$ in the equation $e=ar+br\sigma$ as a kind of temperature coefficient, since the thermo-electromotive force $e$ for a given difference $r$, of temperature, increases linearly with $\frac{\sigma}{2}$, the mean temperature of the junctions.

[59] We shall find below that hardness may also exist in iron-carburets without a marked electrical equivalent.

points is known. Finally it may be called to mind that the direction of the initial tangent at the point "silver" $\left(\frac{da}{ds}\right)_{s=0.017}$ throughout the above results is negative.[60] The thermo-electric effect of the addition of small amounts of other metals to silver would therefore appear to be a progression in a thermo-electrically negative direction.[61] The number of alloys here examined is too small to permit us to attach much significance to this fact. Nevertheless it follows that the thermo-electric relation of any given metal to another does not, so far as can now be seen, enable us to predict the effect produced when the first metal is alloyed to the second. Gold and platinum, for instance, are both positive as regards silver; the initial alloys silver-gold, silver-platinum, however, are negative as regards silver.

## THE GENERAL PHENOMENON OF TEMPER REGARDED FROM THE CHEMICAL AND FROM THE MECHANICAL STANDPOINT.

*Inferences from the behavior of alloys.*—We now desire to consider the bearing of the above results on the electrical properties of steel. From the standpoint of the chemical theory of tempering, it is permissible to regard the linear locus, thermo-electric power varying with resistance, as the initial tangent of a loop of comparatively enormous magnitude. (See figure 13.) The increment of resistance with increasing hardness, or, in other words, with an increase of the ratio of combined to uncombined carbon, is to be considered analogous to the increase of resistance encountered on alloying small amounts of any metal to any given other metal. The linear relation can hardly be regarded striking, since in the case of steel the maximum amount of available carbon does not exceed one to two per cent. Finally, the magnitude of the variation or the extent of the loop might again have been anticipated, from the fact that here a metalloid is alloyed to a metal. The question, therefore, at once suggests itself, in how far these results are corroborated by the electrical behavior of cast-iron. In another paper we will show that the specific resistance of cast-iron, when in a condition corresponding to that of hard steel, *i. e.*, when by means of sudden cooling as much carbon has been converted into the combined form as possible, may be increased to $100\frac{cm}{cm^2}0^\circ$ microhm. That is, the specific resistance of chilled cast-iron is nearly as

[60] The isolated negative value for the two per cent. copper alloy might be regarded suspiciously in consequence of the difficulties encountered in endeavoring to obtain these alloys free of oxygen. But its specific resistance shows no anomalous behavior.

[61] Thermo-electrically negative in Seebeck's sense. Cf. Wiedemann, Galvanismus, 3 ed., p. 248, 1883.

large as that of mercury. Suppose, now, we compare the variation of specific resistance $\left(\text{superior limit } s=50\frac{cm}{cm^3}0^\circ \text{ microhm}\right)$ in the case of steel, where the amount of combined carbon cannot exceed 1 to 2 per cent., with the corresponding variation of specific resistance $\left(\text{superior limit } 100\frac{cm}{cm^3}0^\circ \text{ microhm}\right)$ in the case of cast-iron, where the combined carbon can be increased as high as 5 per cent.; then it apparently follows at once that the electrical behavior of cast-iron is such as we would be justified in predicting from the known relations in case of steel, if we accept the chemical hypothesis of tempering.[62] Hence neither the simple relation of thermo-electric power and specific resistance discovered for steel, nor the phenomenal variation of these constants with the state of hardness of this material, are further to be looked upon as remarkable. We will return to this subject again, below.

It follows from what has been said, that our hope of being able to throw additional light on the nature of the phenomenon of temper in case of steel from a detailed study of the analogous electrical behavior of alloys was not realized. For although on the one hand the new data furnish no results antagonistic to the chemical theory, on the other they leave us without satisfactory or additional reasons for accepting the same. Under these circumstances it is necessary to contrast the theories which may be advanced for the explanation of temper with full regard to all known facts. This we will endeavor to do in the following, particularly so as the discussion will show where good work has been done done and where crucial data are still lacking.[63]

*Electrical resistance a volume function.*—The discussion may be appropriately commenced with the examination of certain mechanical phenomena which accompany hardness in steel. It is known that the effect of tempering to glass-hardness is an increase both of the specific resistance and the specific volume of steel. This, however, is analogous to the effect of temperature in the case of metals generally. The question is therefore at once suggested, in how far a given increment of volume in the case of steel, whether produced by temperature or by tempering will be accompanied by the same increment of specific resistance. We

[62] Cf., however, p. 186.

[63] In this place it will be well to refer to certain memoirs which have a definite bearing on the subject-matter in hand. In addition to Karsten, Hausmann (Molecularbewegungen, 1856, p. 48), Tunner (Leob. Jahrbuch, x, p. 480, 1861), Jullien (Bullet. de la Soc. de l'industrie minérale, I, p. 566; II, p. 202, 644), Hezner (Berg- u. Hüttenm. Ztg., 1862, p. 140), Deville (Dingler's Journal, clxviii, p. 174), Caron (ibid., p. 36) have developed theories on the causes of hardness in steel. For a discussion the reader is referred to Kerl's Metallurgy, 1870, Vol. III, pp. 25–7, translated by Crookes and Röhrig. It is not our object to enter into a critical examination and comparison of these, as we propose simply to consider the inferences which may be drawn from the electrical behavior of iron-carburets.

were fortunate in finding a sufficient number of data in the literature of steel to enable us to make a preliminary calculation or estimate.

Let $v_2$ and $v_1$ denote the specific volume of steel in the glass-hard and soft states respectively. Then the results of Fromme[64] with steel rods whose diameters (0.27 centimeter and less) are nearest those of our own (0.10 centimeter and less) may be thus expressed:[65]

$$\frac{1013}{1000} > \frac{v_2}{v_1} > \frac{1012}{1000} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Suppose we put $v_2 = v\,(1+3\beta t)$, where $\beta = 12 : 10^6$, meaning thereby that the volume-increment $v_2 - v$ is due to an increase of temperature $t$. Then we find

$$360° > t > 330° \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Since $\beta$ will probably increase with temperature, this inequality might approximately be expressed $t = 300°$.

Experiments on the resistance effect of high temperatures were originally made by Müller.[66] By the aid of his data for the resistance of iron at 21°, 285°, "oxide-tints appear" (300° to 350°), we deduce, if $s'$ and $s$ be the specific resistances of steel at 300° and 0°, respectively,

$$3.6 > \frac{s'}{s} > 2.5 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where the superior limit is possibly too small. The more recent results of Benoit,[67] however, furnish us more accurate values. Let $\frac{s'}{s}$ refer to an interval of temperature between 0°—330° and 0°—360°. Then Benoit's special formulæ and constants for steel give us the relation:

$$3.7 > \frac{s'}{s} > 3.4 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

If, finally, $s'$ and $s$ denote the specific resistance of good steel in the glass-hard and soft states, respectively, then our results have shown[68]

$$3.0 > \frac{s'}{s} > 2.5 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

If we compare the estimates expressed in the inequalities (3), (4), (5), it becomes at once apparent that the results of Fromme, together with those of Müller and Benoit, are more than sufficient for the explanation of the enormous increase of resistance which a steel rod tempered to glass-hardness, experiences. It follows that in the case of steel, a given increment of specific volume, whether produced by temperature

[64] Fromme: Wied. Ann., VIII, p. 354, 1879.

[65] These inequalities are not general in their signification. Their purpose is merely that of expressing the extent of the interval within which the cited data were observed to lie.

[66] Müller: Pogg. Ann., CIII, p. 176, 1858. It is hardly necessary to distinguish between iron and steel here.

[67] Benoit: Comptes rend., LXXVI, p. 342, 1873; cf. Carl's Rep., IX, pp. 55–9, 1873.

[68] The predominant influence of carbon on the ratio $\frac{s'}{s}$ will be referred to elsewhere.

or by tempering, is accompanied by increments of specific resistance of the same order. Of course, a result of this kind, since the rod remains homogeneous throughout in one case and is subjected to extremely complicated structural modification in the other, cannot be rigidly true. Nevertheless, the approximate data are of the greatest importance, because they demonstrate conclusively that the effects of the operation of tempering, even if regarded as of a purely mechanical character, must be attended by electrical phenomena of the same order as those which are actually observed.

(2) There is another question intimately connected with the one just discussed, viz, whether a given decrement of volume,[69] produced either by pressure alone or by temperature alone, is always attended by the same diminution of resistance for the same substance (metal); or whether it is necessary to postulate the existence of a purely thermal influence in the second case. Chwolson,[70] who has subjected wires of copper, brass, and lead to pressure, infers that the resistance and the specific volume of these substances vary in like ratio.

In Chwolson's experiments the effects due to pressure are so nearly commensurate with the errors possibly introduced by temperature that we are justified in approaching his results with some diffidence. Marked compression is not readily attainable by piezometric methods. With steel, however, the result, which more than verifies Chwolson's inference on the resistance-effect of volume-reduction, may be thus illustrated.

Let $s_t = s_0 (1+\alpha t)$. Specific resistance ($s_t$) is here regarded as a temperature ($t$) function. Then, if $t$ be supposed to decrease indefinitely, the equation $s_t = 0$ would be satisfied at about

$$t = -250^\circ \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

provided, of course, the given relation holds.[71]

On the other hand, let

$$s_2 = s_1 \left(1 + k \frac{v_2 - v_1}{v_1}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where the specific resistances $s_2$ and $s_1$ correspond, respectively, to the volumes $v_2$ and $v_1$, and $k$ is a constant. Specific resistance is here regarded as a volume-function.

[69] In the case of mercury, for instance. The results for solids would be distorted by the loss of structural homogeneity of the compressed solid resulting from external pressure. Large increment of volume is probably only obtainable by tempering steel, and to this enlargement of mean specific volume the remarks already made apply.

[70] Chwolson, Carl's Rep., XIV, 26, 27, 1878.

[71] The temperature coefficient here accepted is the one found for soft steel in chapter I, p. 19, viz, $\alpha = 0.004$.

In order to estimate the value of $k$, we made a few preliminary experiments, the results of which are contained in this table:[72]

| No. | Temper. | Diameter. | Length. | Specific gravity. | Specific volume. | Specific resistance. | Specific resistance. | $k$ |
|---|---|---|---|---|---|---|---|---|
| | | cm. | cm. | at 20°. | $v_2$: $v_1$ at 20°. | $\frac{cm}{cm^2}0°$ microhm. | $\frac{cm}{cm^2}20°$ microhm. | |
| 2 | Soft | 0.575 | 10.11 | 7.6977 | 1.0000 | 14.3 | 15.5 | 146 |
| 2 | Glass-hard | ..... | ..... | 7.6145 | 1.0109 | 38.6 | 40.2 | |
| 3 | Soft | 0.385 | 10.02 | 7.6117 | 1.0000 | 14.9 | 16.2 | 149 |
| 3 | Glass-hard | ..... | ..... | 7.5289 | 1.0110 | 41.0 | 42.7 | |

It will be observed that, in the calculation of $k$, both $\frac{v_2-v_1}{v_1}$ and $\frac{s_2-s_1}{s_1}$ were taken at 20°, because we as yet possess no data for the reduction of the former ratio to zero. Equation (7) implies, of course, that the same temperature (desirably 0° C.) occurs throughout.

Suppose, now, that by any mechanical means whatever the volume of steel has been isothermally so far decreased that in equation (7), $s_2=0$. Then

$$-\frac{1}{k}=\frac{v_2-v_1}{v_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Such a volume decrement, if the result of diminution of temperature, would correspond to a cooling of steel as far as $[v_t=v_0\,(1+3\beta t)]$,

$$t=\frac{1}{3\beta}\,\frac{v_t-v_0}{v_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

*i. e.*, if the volume decrements in (8) and (9) be identical,

$$t=-\frac{1}{3\beta}\,\frac{1}{k}=-190° \text{ (nearly)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

From a comparison of equations (6) and (10), we therefore again infer that variation of resistance is a necessary concomitant of variation of volume. No matter how the latter may have been produced, whether by temperature or by tempering, the increments of resistance due to a given increment of volume are of the same order. It is probable that this relation will apply to the resistance of non-electrolyzed solids generally. The results for steel are as nearly coincident as the excessively large sources of errors unavoidably encountered permit us to anticipate. In addition to those already enumerated, we need only mention that Fromme worked with a different kind of steel from that used in our researches; that neither the coefficient of heat-expansion nor the galvanic temperature coefficient applies accurately for the large intervals of temperature met with, &c. A special error is introduced in consequence of the difficulty encountered in endeavoring to define values for the soft state.

[72] Rods not thoroughly homogeneous, tempered after heating in a blast-flame.

(3) The results of Fromme[73] and Chwolson finally contain a remarkable analogy, to which attention has not yet been given. If the hardness of a glass-hard steel rod be supposed to decrease continuously, then the specific volume will be found to pass through a minimum, as Fromme has emphasized, at a state of hardness corresponding to the annealing tint, "gray" (annealed at 300°–500°). Chwolson experimented on a very large number of metals and alloys. He found that the electrical effect of "drawn" hardness as well as the hardness due to sudden chilling vanishes on exposure of the hard wire to high temperature, in such a way that after the first gentle ignition at low red heat the specific resistance of all metals passes through a minimum.[74] Unfortunately Fromme has not interpolated a temperature which would produce an effect between "gray annealed" and "soft." Nevertheless it is difficult to avoid the conclusion that in all these examples of minima we encounter phenomena essentially of the same kind. Chwolson remarks that in case of steel his results were singularly striking. It would appear, therefore, that the mechanical effect (electrically measured) of sudden cooling is the same for almost all metals; that the magnitude of this effect differs from metal to metal, and is enormously pronounced in steel. This is the first evidence adduced that the given operation, tempering, produces qualitatively like effects on metals generally, the difference being in degree only.[75]

(4) In view of the increasing importance of density or of the values of specific volume in all these instances, the fact that in the above experiments with alloys the ranges of variation were found to be in the order of the differences of specific volume of the metals composing the alloy may again be called to mind. In case of steel the intimate relationship between specific resistance and thermo-electric power, described elsewhere, suggests that the cause of the increase of volume consequent upon sudden cooling is of a purely mechanical character, *i. e.*, that it is not the direct result of the change of chemical condition of steel which tempering probably produces.

*"Drawn" hardness.*—Matthiessen[76] found that a hard-drawn wire of silver could be very perceptibly annealed (conductively decreased) by continued boiling in water. We obtained a good corroboration of this

[73] Fromme, l. c.

[74] Lead and German silver are exceptions.

[75] It must be borne in mind that this remark refers to the electrical indication of the (mechanical) effect of tempering. It is well known that while sudden chilling hardens steel, it is said actually to soften some of the other metals. It is, however, exceedingly difficult to distinguish between the degrees of hardness of brass or copper suddenly chilled or slowly cooled from red heat, by ordinary mechanical means; and, moreover, sudden cooling may be accompanied by purely chemical effect in alloys and (not chemically pure) metals as it is in case of steel.

[76] Matthiessen, und v., Bose: Pogg. Ann., CXV, p. 363, 366, 370, etc., 1862.

result with drawn German-silver wire,[77] in which, after an exposure to steam at 100° of only an hour, a change of resistance of about 0.25 per cent. was perceptible. It follows, therefore, that not only tempered but drawn wires may be annealed to a very marked degree at comparatively low temperature.

*Inferences from the behavior of iron-carburets.*—(1) In chapter I we saw that the temperature-coefficient of cast-iron is in good accordance with the coefficients of wrought iron and of steel in different states of temper, so that in this respect all the iron-carburets form a single connected series.

(2) This is by no means the case if we compare the relative galvanic and thermo-electric behavior of these products. From an inspection of figure 13 it is at once obvious that the position of cast-iron is isolated relatively to the linear locus which obtains for steel. This observation shows conclusively that in the case of steel the cause of the electrical variation in question must be essentially different from that which determines the position of cast-iron. Below it is shown to be necessary to explain the distinctive electrical qualities of cast-iron as effects of chemical composition. Hence we infer with some assurance that the electrical behavior of steel on passing from one state of temper to another, since the succession of values in no way suggests the electrical qualities of cast-iron, is conditioned by the cotemporaneous and purely mechanical changes which steel undergoes.

*Phenomena of annealing chemically interpreted.*—On endeavoring to use the chemical hypothesis of tempering to account for the phenomena of annealing,[78] we at once encounter serious difficulties. On the basis of this theory there must exist a fixed ratio of combined to uncombined carbon for each temperature of the annealing bath. Moreover, for a given temperature this ratio must be approached gradually (asymptotically) as time of exposure is prolonged indefinitely; for different temperatures it must decrease as temperature increases indefinitely, until finally a minimum value wholly independent of temperature is asymptotically reached.[79] The minimum of the ratio of combined to uncombined carbon need not, of course, be zero. The last phase of this species of decomposition is in many respects similar to the phenomena of dissociation. The resemblance can, however, only be apparent, since continuous dissociation has not been observed except in the case of gases. At least, in our knowledge, there are no chemical examples in

[77] The results are these: Before boiling: 12°.4, $r$=6.8522; 12°.5, $r$=6.8523; 12°.6, $r$=6.8524. During boiling: 99°.8, $r$=7.0167, $r$=7.0182, $r$=7.0204; resistance ($r$) measured successively. After boiling: 13°.5, $r$=6.8691; 13°.6, $r$=6.8694; 13°.7 $r$=6.8696.

[78] Strouhal und Barus: Wied. Ann., XI, p. 962, 1880.

[79] In these cases of annealing slow cooling of the annealed rod after exposure to the annealing temperature is always presupposed. It is thus that annealing at red heat is synonymous with softening ("Ausglühen"). This operation does not, however, convert all the carbon in steel to the uncombined form, in which case the said ratio would be zero.

which solids are found to dissociate in accordance with the laws to which gases, in virtue of their physical state, must conform; and for this reason the explanation of the phenomena of annealing given by the chemical theory is remote and forced, and to be discarded. We gain no more by adopting Matthiessen's hypothesis, which considers all iron-carburets as solidified, more or less thorough solutions of carbon in iron.

*Annealing physically interpreted.*—It is not difficult, however, to find for the phenomena of annealing a satisfactory explanation of a purely mechanical character. We proceed in a manner analogous to the way in which, in the case of soft rods of the same dimensions, what is known as coercive force[80] in magnetism is sometimes defined. To this analogy we will recur again.

(1) It will be permissible in this place to introduce a definition of viscosity which is conveniently adapted to our present purposes. We will suppose the viscosity of steel to be measured by the maximum of strain of a given kind (in the present research the strain accompanying hardness) which a steel rod of given dimensions, after previous condition of supersaturation, of itself, permanently retains. The process of tempering to glass-hardness, therefore, is essentially one by which energy is stored up, whereas during the operation of annealing the stored energy is again more or less gradually expended; and the maximum energy permanently potentialized, under given circumstances of temperature (the same rod always presupposed), increases directly with the maximum intensity of permanent strain under the same circumstances. Practically, however, we possess no means for the absolute evaluation of either of these quantities. But in so far as both thermo-electric hardness and specific resistance (the rod being in the state of the maximum of permanent hardness as regards the given temperature) vary directly with strain and stored energy, we may accept either of the former quantities as furnishing a good general estimate of the magnitude of the latter. In the case of one and the same steel wire viscosity is an inverse function of temperature and of temperature only. In the case of wires which differ quantitatively though not qualitatively as regards carburation, and are otherwise identical, viscosity is a function both of temperature and carburation (carburation $< 2$ per cent.), decreasing with the former and increasing with the latter magnitude.

(2) The difference between the phenomena of annealing and the phenomena of viscosity, as ordinarily studied and observed, is succinctly this, that in the latter case stress or a single force is applied from without to produce the gradual and permanent deformation through infinite time; in the former, however, stress exists in the rod itself (strain of hardness), but can be made to disappear in the asymptotic way characteristic of these phenomena by decreasing the viscosity of the rod as a whole; *i. e.*, increasing its temperature. In other words, in the ordinary

[80] Cf., for instance, Mousson: Physik, 2 ed., Vol. III, p. 86.

case of viscosity-measurement the phenomenon is evoked by sudden application of stress (torsion, tension, flexure, volume-compression) at constant viscosity; in the present case by sudden decrement of viscosity at initially constant stress. For instance, given a glass-hard rod at ordinary temperatures. Let its temperature be raised to 100°. The stress which was just permanently maintained at the lower temperature is in excess at the higher, because of the diminished viscosity of the rod, as a whole; and this excess must therefore disappear gradually through infinite time, precisely as we have observed it. If, furthermore, the diminution of viscosity be sudden and very large (annealing at high temperatures 200°, 300°, &c.), stress will disappear at a correspondingly rapid rate; etc.

In this way we are able, as a first approximation, to refer the phenomena of annealing to the general category of phenomena of viscosity. But for the reason of the deformation accompanying the existence of internal stress, for the reason that the degree of heterogeneity of a hard rod varies to a greater or less extent with each variation of stress as well as temperature, it is difficult to form any clear conception of the viscosity of the rod, as a whole, except by the aid of such a definition as is given at the beginning of the present paragraph. We will waive a further development of these views here for the reason that the details of operation of tempering itself are in need of further experimental elucidation, in various directions. Here, however, an account of the occurrences which rob the theory just sketched of much of its clearness and perspicuity is in place.

(3) The most satisfactory conception which we can form of the nature of the strain of a glass-hard steel rod is that of abnormally condensed external layers surrounding, like an arch, an abnormally rare core. These two abnormal states of density mutually condition each other. It is the stress under which the internal layers exist which is the cause of the condensation of the relatively thin external shell, and the extreme limit of condensation of the latter, again, which prevents the internal layers from falling back to normal density. This view has much experimental evidence to support it,[81] though it must be regarded as a mere *diagram* of the essential features of the vastly more complicated structure of the glass-hard rod. An increase of the temperature of a hard rod (annealing) is antagonistic to the existence of a strain of this character in two respects. In the first place it is obvious that the rare core will be in a condition of less intensity of strain at a high than at a low temperature, and this because of the volume-expansion due to temperature. For instance, the temperature may readily be chosen so high that an identical hot rod would normally have the same low density that originally existed in the strained core of the cold glass-hard rod. Increase of temperature, on the other hand, diminishes the den-

[81] Cf. Mousson: Physik, 2. ed., pp. 224, 225, Vol. I, 187. Fromme: l. c.

sity of the external layers. In proportion, therefore, as the temperature of the annealing bath is higher, the inner layers of the originally hard rod approach the normal density for the respective temperatures more and more nearly, and the surface condensation, because the conditions of its existence are being annulled, must therefore also disappear at a corresponding rate. When the temperature, $t^0$, at which the stress in the inner layers is wholly gone has been reached, only as much of the surface condensation can have remained as is in conformity with the ordinary viscosity of steel at $t^0$. The rod if cooled from $t^0$ will therefore in the cold state be of greater density than an otherwise identical and homogeneous rod—it being postulated, of course, that with the disappearance of strain the tempered rod itself approaches nearer and nearer the homogeneous state. If the annealing be carried to even higher temperatures than $t^0$, the surface condensation will also more and more fully vanish, and the density of the cold rod as a consequence again decrease. Now, it is exceedingly remarkable and significant that the electrical effects due to the annealing of a glass-hard steel rod, enormous as they are, vanish almost entirely after the temperature of the annealing bath exceeds 300° to 400°, that, is at a temperature at which the density of a homogeneous hot rod is the same as the density of an identical cold glass-hard rod,[82] or, in other words, very nearly at the temperature $t^0$ just discussed.[83] Magnetic effects, however, as will be shown elsewhere, are still very marked for rods annealed at temperatures higher than $t^0$. This is in conformity with the hypothesis of residual surface condensation, because magnetic phenomena are so largely dependent on the external layers of a rod. Finally, the actual existence of a maximum of density for rods annealed at temperatures near $t^0$ has been experimentally shown by Fromme.[84]

(4). With these remarks, however, the subject is by no means fully exhausted, even so far as our present purposes go. It is easily conceivable that a rod at 400° may be brought into a condition of strain (strain of hardness) which bears the same relation to an identical homogeneous rod at 400° that an ordinary glass-hard rod does to an identical cold soft rod. We believe, however, that the viscosity of the hot rod is too insignificant to admit of the permanent retention of more than reduced intensities of stress, no matter how much of the strain peculiar to temper may by some ideal means[85] have been imparted to it. In other words, suppose that a sufficient and very great intensity of

[82] Cf. pp. 90–93.

[83] The condensed layers of the rod being thin in comparison with the rarefied parts.

[84] Fromme: l. c., p. 355.

[85] To form a definite conception of an ideal process of tempering like the one in question, suppose the observer to have in control a set of forces, by aid of which he is able to move each of the molecules of a (soft) steel rod into such positions that the rod, as a whole, experiences a strain of glass-hardness of very great intensity. When this characteristic distribution of molecules within the volume of the (now) hard rod has been effected, let the action of the said forces be discontinued and the molecules

the strain in question is imparted both to an iron and to a steel rod of the same dimensions. When the tempering influence has ceased, the steel rod will have retained a phenominal amount and exhibit glass-hardness. The iron rod, on the contrary, will have lost nearly the whole of it. Analogous to the latter, the steel rod when at 400°, no matter how much stress may be imparted to it, will permanently retain no more at 400° than the small amount which is consistent with the definition of viscosity above given.[86] The present consideration, therefore, culminates in an experimental inquiry which may be formulated thus: Will a steel rod, if chilled from a given temperature in red heat in a liquid at any temperature below $t^0$, and subsequently annealed by an exposure to $t^0$, indefinite as regards time, always exhibit the same final intensity of stress or thermo-electric hardness—barring of course all secondary effects, such as are due to decarburation, etc.

## THE PHENOMENON OF GLASS-HARDNESS DISCUSSED FROM THE CHEMICAL AND FROM THE MECHANICAL STANDPOINT.

*Chemical interpretation.*—We now proceed to the discussion of the effects of sudden chilling on steel. If we endeavor to explain the known phenomena mechanically, we encounter two grave difficulties. In the first place, we fail to find any obvious reason why the hardness of a chilled rod is not, as Chernoff[87] discovered, a uniformly continuous function of the temperature of the rod before sudden cooling. In the second place, the important function of carbon in the process of tempering, and the necessary presence of this element in steel if the effects of sudden cooling are to be permanent, is not easily discernible. Both these apparently weak points of the mechanical theory may be very easily explained chemically. It is only necessary to suppose that a certain high temperature must be reached before the uncombined carbon of soft or annealed rod is again either converted into the combined form or is dissolved.[88] That such a temperature would lie, at lowest, in the

left to themselves. Then will the excess of stress gradually disappear, until, through infinite time, the intensity of strain which the given rod under the given circumstances of temperature of itself can just permanently retain, is reached. The (hard) rod is now in a condition of stable molecular equilibrium. The close analogy between this ideal method of imparting temper and magnetization is at once apparent.

[86] Cf. p. 95, (1).

[87] Chernoff: Vortrag geh. in der Russ. Tech. Gesell., April u. Mai, 1878; cf. Jeans, op. cit., p. 644–7. A reprint of Chernoff's lecture kindly sent by the author showed us that Chernoff was the first to discover the remarkable phenomenon in question. Our own experiments, made independently of Chernoff and shortly after him, led to the same result, both as regards mechanical and thermo-electric hardness. (Cf. Barus; Wied. Ann., VII, p. 405, 1879; Strouhal and Barus: Wied. Ann., XI, p. 946, 1880.)

[88] Cf. Karsten's theory on the existence of a "polycarburet," for instance, in Percy-Wedding, op. cit., p. 167; Jeans, op. cit., p. 646; etc.

region of red heat is immediately probable. Sudden cooling from temperatures below this critical value, in so far as carbon would remain undissolved or uncombined, could not impart hardness to steel, but would merely anneal it the more thoroughly—which is actually observed. It is particularly to be noted here, moreover, that, according to Jeans, in the cementation process iron will not absorb carbon until a certain definite high temperature has been reached.

*Physical interpretation.*—(1) The first of the above-mentioned difficulties encountered by a mechanical theory must here be discussed with greater detail. The phenomenon is not without remarkable physical analogies. Cumming,[89] for instance, and after him others, called attention to the very sudden expansion exhibited by iron at a certain temperature in red heat. Tait[90] signalizes the abnormal thermo-electric behavior of iron under the same circumstances. Finally, the discovery due to Gore,[91] which Baur[92] has recently studied with considerable detail, is to be cited here, viz., that the temporary magnetism of saturated iron at the said temperature suddenly vanishes from a foregoing very large value. There appears to be little reason to doubt that all of these phenomena are different manifestations of the same cause.[93]

(2) If, now, we bear in mind that a glass hard rod has retained a very large part of the increment of volume due to the heat expansion, at the temperature from which it was chilled; that furthermore very rapid cooling is the necessary condition of the appearance of glass-hardness; then the remarks just made at once suggest the inference that Cumming's phenomenon plays a very important part in the process of tempering. It would follow, furthermore, that the said phenomenon must first fully have appeared if sudden cooling is to be accompanied by hardness. Hence the necessity of a critical temperature. Here, therefore, we encounter the first difference between iron and steel on the one hand, and all other metals and alloys on the other (these being without the said phenomenon), as regards conditions favorable to the production of hardness by chilling.

(3) The difference between iron and steel, however, appears even at ordinary temperatures whenever both materials are subject to the same kind of stress. If, for instance, we expose two like rods, one of iron and

[89] Cumming: Cf. Tait, l. c. Gore: Proc. Roy. Soc., XVII, 260, 1869.

[90] Tait: Trans. Roy. Soc., Edinbgh., XXVII, 1872-73, p. 125; Proc. R. S. E., VIII, p. 32, 1872–73.

[91] Gore: Phil. Mag., (4), XXXVIII, p. 59, 1869; *ibid.*, XL, p. 170, 1870.

[92] Baur: Wied. Ann., XI, p. 408, 1880.

[93] Tait refers the sinuous and broken character of the iron line in his thermo-electric diagram to Cumming's phenomenon. Gore, and more thoroughly Baur, ascribe the anomalous behavior of temporary magnetism at red heat to the same cause, in both cases attributed to Gore. The same irregular results would probably recur in the variation of electrical conductivity on passing the temperature in question. The method of experimentation adopted by Benoit (l. c.) led him to overlook this. With the discovery of Chernoff these interesting analogies are enriched by a new fact.

one of steel, to the influence of the same sufficiently intense magnetic field, the steel rod, after withdrawal, is found to have retained a very considerable part of its original magnetism permanently, whereas the iron is comparatively unmagnetic. Analogously we find that, although both iron and steel possess the essential property of sudden expansion at red heat discovered by Cumming, steel after sudden cooling has retained a phenomenal amount of the peculiar and characteristic strain accompanying hardness, while iron remains nearly soft and comparatively homogeneous. It appears, therefore, that the effect of sudden cooling on steel also admits of a physical explanation.

*Physical and chemical changes simultaneous.*—There is one other consideration to be added here. If we compare the difference between steel and iron as regards their power for the retention of a given mechanical strain, with the respective retentive properties of steel at different temperatures, we may readily infer that under all circumstances the absolute amount of combined carbon in iron or steel is the essential factor. From this standpoint every gradually progressive change of strain from any original to any final value is to be looked upon as a physical phenomenon; the fundamental cause of such gradual change of strain, in other words the cause for the necessary change of viscosity, is to be regarded as only dependent on temperature in such measure as temperature itself determines the ratio of combined to uncombined carbon; hence, also, the amount of combined carbon in the steel rod. Here, therefore, the thermo-electric hardness of a rod annealed for an indefinite length of time at $t$ degrees is an indication of the amount of combined carbon in the rod at this temperature.

## EXPERIMENTS WITH MALLEABLE CAST-IRON.

*Above inferences not decisive.*—Endeavoring to review the above matter with the object of obtaining data for the discrimination between the physical and the chemical features of the process of tempering, we fail to find criteria sufficiently decisive to enable us to draw our inferences satisfactorily. We are induced even to acknowledge that there exists a remarkably intimate relation between the two methods of interpreting the various phenomena; for not only are we able to explain even the more important details both from the chemical and the physical standpoint, but the development of either hypothesis continually suggests new means for the development of the other.

*Electric behavior of malleable cast-iron.*—At this stage of our research it appeared probable that further and perhaps critical information might be obtained from a study of the electrical behavior of different species of cast-iron. We commenced our inquiry with an examination of what

is known as "malleable cast-iron,"[94] a material which from its exceptional position in the series of iron-carburets seemed particularly well adapted for the elucidation sought. This product is tough and tenaceous, though imperfectly malleable in the soft state, but after sudden cooling from red heat becomes almost as hard and certainly quite as brittle as hard steel. Forquingnon[95] has shown that it is distinguished from steel, chemically, by the relatively very large amount of graphite which it contains. We were fortunate in obtaining rods of malleable cast-iron from M. E. Hartmann, in Würzburg.

The results of our measurements of thermo-electric power are given in the following table (42) on a plan identical to that adopted above for alloys. The rods were examined in three states of hardness, viz., in the commercial condition in which they reached our hands, then immediately after sudden chilling, finally after thorough annealing (softening) by slow cooling from red heat:[96]

TABLE 42.—*Thermo-electric power of malleable cast-iron.*

| Rods. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|
| ROD No. 1. | C. | C. | *microvolt.* | *microvolt.* | | | |
| Original condition | 18.3 | 79.7 | −57.3 | −57.2 | −0.1 | | |
| | 18.4 | 68.8 | −39.4 | −39.2 | −0.2 | | |
| | 18.5 | 58.3 | −25.0 | −25.1 | 0.1 | +0.45 | −0.014 |
| | 18.6 | 47.4 | −13.4 | −13.7 | 0.3 | | |
| | 18.7 | 38.2 | − 7.0 | − 6.8 | −0.2 | | |
| Chilled hard | 15.7 | 59.0 | −81.6 | −80.8 | −0.8 | | |
| | 15.7 | 51.2 | −62.5 | −62.7 | 0.2 | | |
| | 15.7 | 43.4 | −45.6 | −46.2 | 0.6 | −0.90 | −0.013 |
| | 15.7 | 36.7 | −33.0 | −33.2 | 0.2 | | |
| | 15.7 | 30.1 | −21.8 | −21.6 | −0.2 | | |
| Soft | 17.9 | 86.1 | −69.8 | −68.5 | −1.3 | | |
| | 17.9 | 77.2 | −52.3 | −53.0 | 0.7 | | |
| | 17.9 | 66.5 | −36.3 | −36.9 | 0.6 | +0.30 | −0.013 |
| | 17.9 | 53.9 | −21.5 | −21.6 | 0.1 | | |
| | 17.9 | 43.1 | −11.9 | −11.7 | −0.2 | | |
| ROD No. 2. | | | | | | | |
| Original condition | 16.8 | 75.9 | −14.3 | −15.2 | 0.9 | | |
| | 16.9 | 66.3 | − 7.1 | − 6.4 | −0.7 | | |
| | 17.0 | 56.1 | 0.0 | + 0.1 | −0.1 | +0.98 | −0.013 |
| | 17.0 | 45.2 | + 3.7 | + 4.2 | −0.5 | | |
| | 17.1 | 37.2 | + 5.5 | + 5.1 | 0.4 | | |
| Chilled hard | 12.0 | 53.9 | −25.5 | −24.4 | −1.1 | | |
| | 12.2 | 46.3 | −15.4 | −16.3 | 0.9 | | |
| | 12.3 | 40.9 | −11.1 | −11.5 | 0.4 | +0.37 | −0.014 |
| | 12.4 | 35.5 | − 7.6 | − 7.4 | −0.2 | | |
| | 12.5 | 30.3 | − 4.6 | − 4.4 | −0.2 | | |
| Soft | 18.2 | 86.1 | −43.7 | −43.8 | 0.1 | | |
| | 18.2 | 72.3 | −25.5 | −25.2 | −0.3 | | |
| | 18.3 | 55.5 | − 9.5 | − 9.1 | −0.4 | +0.72 | −0.013 |
| | 18.3 | 45.1 | − 2.4 | − 3.0 | 0.6 | | |
| | 18.3 | 35.1 | + 0.1 | + 0.3 | −0.2 | | |

[94] Cf. Perry-Wedding, *op. cit.*, p. 143.

[95] Forquingnon, *l. c.*, p. 536.

[96] The usual process of surrounding the rods with ferro-ferric oxide in gas-pipe (closed), then heating the latter to redness in a charcoal furnace, in which the tube is left until the fire is completely extinguished, being adopted.

TABLE 42.—*Thermo-electric power of malleable cast iron*—Continued.

| Rods. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|
| ROD No. 3. | C. | C. | *microvolt.* | *microvolt.* | | | |
| Original condition | 16.1 | 67.3 | 7.6 | 6.8 | 0.8 | | |
| | 16.2 | 62.0 | 8.3 | 8.6 | −0.3 | | |
| | 16.2 | 50.3 | 9.6 | 10.6 | −1.0 | 1.00 | −0.019 |
| | 16.3 | 43.7 | 10.5 | 10.4 | 0.1 | | |
| | 16.3 | 37.3 | 9.5 | 9.2 | 0.3 | | |
| Chilled hard | 17.8 | 58.2 | −22.9 | −22.1 | −0.8 | | |
| | 17.9 | 51.1 | −14.0 | −14.4 | 0.4 | | |
| | 17.9 | 44.9 | − 8.8 | − 9.0 | 0.2 | 0.73 | −0.017 |
| | 17.9 | 37.9 | − 4.2 | − 4.2 | 0.0 | | |
| | 17.9 | 31.2 | − 1.4 | − 1.3 | −0.1 | | |
| Soft | 18.9 | 80.2 | −31.0 | −29.6 | −1.4 | | |
| | 18.9 | 66.1 | −10.8 | −12.0 | 1.2 | | |
| | 18.9 | 53.1 | − 0.6 | − 1.3 | 0.7 | 1.15 | −0.016 |
| | 18.9 | 42.1 | + 2.8 | + 3.3 | −0.5 | | |
| | 18.8 | 33.2 | + 4.1 | + 4.1 | 0.0 | | |

The following and final tables (43) contain our results for the specific resistance of malleable cast iron in each of the three states—commercial, chilled hard, annealed soft (at red heat). In column third is given the actual resistance per meter of rod at the temperature $t$. The sections in $cm^2$ are found under $q$. The specific resistances at $t$ and 0 degrees are arranged under $s_t$ and $s$, respectively, while the intermediate column $\alpha$ contains the temperature-coefficients for this reduction:

TABLE 43.—*Electrical resistance of malleable cast iron.*

| Rod. | Remarks. | W $1_m$ | $t$ | $q$ | $s_t \frac{cm}{cm^2} t°$ | $\alpha$ | $s \frac{cm}{cm^2} 0°$ |
|---|---|---|---|---|---|---|---|
| | | *ohm.* | C. | $cm^2$ | *microhm.* | | *microhm.* |
| 1 | Original condition | 0.0274 | 15.5 | $(0.308)^2$ | 26.0 | 0.004 | 24.4 |
| | Chilled hard | 377 | 11.5 | $(0.302)^2$ | 34.3 | 0.004 | 32.7 |
| | Soft | 290 | 14.5 | $(0.290)^2$ | 24.4 | 0.004 | 23.0 |
| 2 | Original condition | 0.0262 | 15.5 | $(0.307)^2$ | 24.8 | 0.004 | 23.3 |
| | Chilled hard | 323 | 11.5 | $(0.300)^2$ | 29.2 | 0.004 | 27.9 |
| | Soft | 285 | 14.5 | $(0.296)^2$ | 25.0 | 0.004 | 23.6 |
| 3 | Original condition | 0.0262 | 15.5 | $(0.303)^2$ | 24.1 | 0.004 | 22.6 |
| | Chilled hard | 316 | 11.8 | $(0.297)^2$ | 27.9 | 0.004 | 26.6 |
| | Soft | 290 | 14.5 | $(0.290)^2$ | 24.4 | 0.004 | 23.0 |

In the following digest the main data obtained for malleable cast-iron are given in more perspicuous form. $\Delta a$ contains the range of variation of the thermo-electric constant $a$ from soft to hard. $\Delta s$ has the same signification as regards specific resistance:

TABLE 44.—*Thermo-electric power and specific resistance of malleable cast-iron.*

| Rod number. | Thermo-electric power ($a$). | | Specific resistance. | | $\Delta a$ | $\Delta s$ |
|---|---|---|---|---|---|---|
| | Soft. | Hard. | Soft. | Hard. | | |
| 1 | +0.30 | −0.90 | 23.0 | 32.7 | −1.20 | +9.7 |
| 2 | +0.72 | +0.37 | 23.6 | 27.9 | −0.35 | +4.3 |
| 3 | +1.15 | +0.73 | 23.0 | 26.6 | −0.42 | +3.6 |

*Decisive character of the evidence.*—The first striking feature of the last set of results is the slight thermo-electric difference between the malleable cast-iron rods and silver. Hence the large values of thermo-electric hardness corresponding to the large values of specific resistance.

Far more remarkable, however, are the almost insignificant variations ($\Delta a$ and $\Delta s$) produced by sudden cooling. Here, therefore, we have a valuable example of an iron-carburet in which the interval of mechanical hardness due to tempering; *i. e.*, the difference of mechanical hardness between hard and soft is very great, whereas the corresponding change of the electrical constants scarcely reaches the electrical difference between "blue annealed" and "soft" for steel. In this respect, therefore, these measurements have critical value. It follows that the mechanical hardness possessed by chilled steel cannot be the only or even the principal cause of the enormous variation of the electrical constants; that the said cause of these variations must be sought in the secondary phenomena which accompany the presence of hardness; that they are therefore very probably due to the strains manifesting themselves, as a whole, in the volume expansion of hard steel.

This important deduction is further substantiated by certain experiments made with cast-iron by Joule.[97] His results showed that cast-iron in the white, hard condition is thermo-electrically nearest antimony; in the black,[98] graphitic condition, however, nearest bismuth. All other samples of cast iron examined occupied thermo-electric positions between these limits. If, therefore, the shifting of thermo-electric position produced by sudden chilling were to be ascribed to the conversion of uncombined into combined carbon, hard steel, like white cast-iron, would lie nearest antimony, soft steel nearest bismuth, whereas the actual positions of steel in these two extreme states of hardness is just the reverse of this. Hence it would follow, again, that the change of thermo-electric power of steel due to tempering must be referred to the increase of volume simultaneously experienced. In striking accordance with this inference are the results of Forquignon:[99] "Le fonte malléable se distingue de l'acier par ses *faible allongements* et sa forte teneur en graphite." It appears, therefore, that here again the absence of marked volume increase is the concomitant of the absence of marked electrical variation.

If we add to these deductions the remarks made in pages 89, 95, and 99, we arrive at the following final result: The existence of the peculiar strain accompanying hardness in steel is the cause of electrical effects so enormous that such additional effects which any possible change of carburation may involve can be wholly disregarded, and all electrical results interpreted as due solely to variations in the intensity of the said strain.

[97] Joule: Phil. Trans., 1859, I, p. 97.

[98] That is, black at the surface of fracture, known to be rich in graphite.

[99] Forquignon, l. c., p. 536.

## CHAPTER IV.

### ON THE THERMO-ELECTRIC EFFECT OF MAGNETIZATION.

*Earlier results.*—A number of facts go to prove that the molecular structure of an iron-carburet is materially affected both by the intensity and by the kind of magnetization which it receives. We know, moreover, from experiments of Joule,[100] Wertheim,[101] Mayer,[102] that the existence of magnetism in a bar exerts a stress bearing some analogy to a pull in the direction of the magnetic axis. This strain seems to be an inseparable concomitant of the magnetic quality. We therefore infer at once that if two identical steel rods be magnetized to different intensities, their original thermo-electric powers will have changed; that, moreover, the increments of this quantity in the two cases, in accordance with the difference of magnetic state premised, will be unequal. Similar remarks possibly apply to other physical constants of steel, in particular to its electrical conductivity. With regard to the latter, the results of earlier observers are either unsatisfactory or discordant.[103] The experiments of Beetz[104] furnish the first evidence of a decisive character. This physicist found that the resistance effect of longitudinal magnetization is an increment of from 0.03 per cent. to 0.06 per cent.; that in the case of transverse magnetization, however, no variation (greater than 0.0005 per cent.) is appreciable. Beetz's result has been corroborated and supplemented by experiments of Auerbach,[105] who maintains that while the specific resistance of hard steel increases continuously from the longitudinally to the circularly magnetized state, soft iron and soft steel possess a minimum of resistance when unmagnetic.

The discovery of a thermo-electric effect of magnetization is due to Sir W. Thomson,[106] and his experiments furnish the only results on the subject which have thus far been obtained. He found that an iron wire in the longitudinal or in the transversely magnetized state is thermo-electrically positive or negative,[107] respectively, when compared with the

[100] Joule: Phil. Mag., XXX, pp. 76, 225, 1847.

[101] Wertheim: Ann. d. Chim. et de. Phys. (3), XXIII, p. 302, 1848.

[102] Mayer: Phil. Mag. (4), XLVI, p. 177, 1873.

[103] Cf. digest and partial discussion in Wiedemann's Galvanismus, II *a*, p. 586 (ed. 1874).

[104] Beetz: Pogg. Ann., CXXVIII, p. 202, 1866.

[105] Auerbach: Wied. Ann., V, p. 289, 1878.

[106] Thomson: Phil. Trans., III, p. 722, 1856.

[107] In Seebeek's sense. See preface.

same wire in the unmagnetic state; that is, there would be a thermo-current from transversely magnetic to unmagnetic through hot, or from unmagnetic to longitudinally magnetic through hot.

*Relative electrical effects of hardness and magnetization.*—These facts have an immediate bearing on the question in how far the method for the measurement of hardness which we employed in the case of unmagnetic rods is to be modified when we deal with magnets. For it is obvious, if the hardness of a steel rod is to be expressible in terms of its thermo-electric power, that magnetization, in so far as it produces no appreciable change of the mechanical quality, must to an equal extent be without influence on the value of its electrical equivalent.

The effect of transverse and of circular magnetization on the specific resistance is not distinctly marked. Beetz, *l. c.*, obtained no indication whatever. We are justified in accepting a similarly small interval of variation for the thermo-electric power, although Thomson, *l. c.*, was able to adduce conclusive experimental proof of its existence. In its bearing on the especial purposes of the present series of papers, this effect is, however, of secondary importance; for which reason, and in view of the difficulties with which an exact measurement would be surrounded, we determined to neglect it in favor of the much more pronounced phenomenon now to be considered.

It is the evaluation of the electrical effect of longitudinal magnetization, therefore, which is carefully to be essayed. As regards the specific resistance, the results of Beetz furnish the datum of only about a half-tenth per cent. for iron in the most favorable case. Now the resistance effect of glass-hardening is as high as 300 per cent. It is obvious, therefore, that where the specific resistance is used for the definition of hardness of steel, the effect of magnetization is thoroughly negligible, since for steel it will probably fall even below the small value for iron; particularly so where permanent magnetism is alone of interest. Consequently this mode of measurement of hardness may be immediately applied to steel irrespective of its magnetic state.

In considering the thermo-electric behavior of steel in its dependence on magnetization, the following striking peculiarity is conspicuous at the outset. When the simultaneous variation of thermo-electric power and specific resistance is produced by tempering, the result is such that steel for continually increasing resistance moves constantly toward greater thermo-electrically negative values. When the simultaneous variation in question is produced by magnetization, however, a positive increment of resistance (Beetz) corresponds to a shifting of steel towards thermo-electrically positive values (Thomson). This at once points out a radical difference between these phenomena, a difference, however, which might have been anticipated both from the utter dissimilarity of the strains, as well as from the fact that we necessarily deal with steel only in the first case, but with iron and steel (soft) respectively, in the

second—where, moreover, the behavior of soft and of hard steel is not even qualitatively the same (Auerbach).

The magnetic result admits of the following interpretation. It has been stated that one of the results of magnetization is elongation in the direction of the magnetic axis and contraction at right angles to it in such proportions as leave the volume of the iron unchanged (Joule). In this respect the stress is analogous to a pull. Now, Thomson discovered in the one case a current from transversely magnetized to longitudinally magnetized iron through hot; in the other a current from transversely strained to longitudinally strained iron through hot. Possibly, therefore, we have in hand more than an incidental coincidence. It is to be noted that both results apply for elongation within the elastic limits.[108]

*Method of experimentation.*—Thomson's results are qualitative. For our purposes, however, quantitative results are a necessity. With the object of deriving these the following experiments were made. The disposition of apparatus is diagrammatically given in Fig. 14. A soft iron

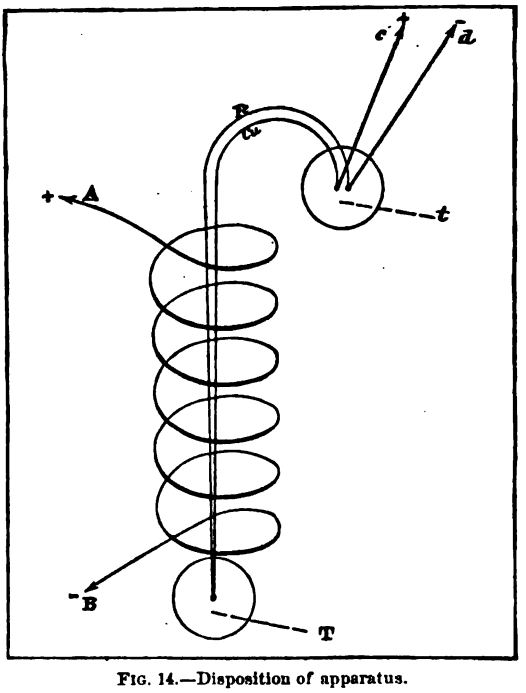



FIG. 14.—Disposition of apparatus.

wire about 0.08 centimeter thick and 40 centimeters long, the ends of which had been fastened to long terminals (*c*, *d*) of copper wire, was

[108] Thomson, *l. c.*, pp. 712, 713. Cohn, Wied. Ann., VI, p. 385, 1879. Beetz (Pogg. Ann., CXXVIII, p. 193, 1866) remarks that the resistance effect of magnetization is probably to be referred to the occurrence of the magnetic strain, and in so far anticipates the above statement. But he possesses no direct evidence.

thrust through a helix ($AB$) together with one of the copper wires, and fixed in its axis. At each of the ends of the helix, and as near its center as possible, a doubly tubulated spherical receiver, containing petroleum at the temperatures $t$ and $T$, respectively, was placed. These receivers contained the junctions of the thermo-element (copper-iron). In other respects the disposition and method of measurement was the same as that employed in the previous chapter II, and the reader desiring further information is referred thither.[109]

The helix in question had a length of 22.3 centimeters, contained ten layers, each with about 55 windings of thick copper wire 0.3 centimeter in diameter.

A Siemens dynamo-electric machine was at our disposal as a source of strong current, the intensity of which, obtained by the aid of a large tangent compass, under the given circumstances proved to be

$$i=3.12\frac{gi\ cmi}{sec}$$

Let $2a$ be the length, $r$ the radius of a given layer of the helix, $n$ the number of turns of wire in the layer, $2b$ the length of the rod to be magnetized. Then will the magnetizing force on the axis of the helix and at a distance $b$ from its center be

$$X_b=\frac{\pi ni}{a}\left[\frac{a+b}{\sqrt{(a+b)^2+r^2}}+\frac{a-b}{\sqrt{(a-b)^2+r^2}}\right]$$

and the mean magnetizing force of this layer referred to the given length ($2b$) of wire

$$X=\frac{\pi ni}{ab}\left[\sqrt{(a+b)^2+r^2}-\sqrt{(a-b)^2+r^2}\right]$$

The following are the data describing the field actually used:

$$\Sigma X_b=35 \qquad \Sigma X=528 \qquad \frac{gi}{cmi\ sec}$$

It is unfortunate that the conditions of a more uniform field could not be secured. But in view of the very large central intensities ($X_0=940$) the belief is warranted that the maximum of magnetization must at least have been very nearly attained. A uniform field of the intensity, 130 to 140, is usually regarded as sufficient to magnetically saturate iron. Our mean value (528) is about four times as large.

The actual measurement of the influence of magnetization on the thermo-electric power of iron was made in such a way that two separate series, each of five observations of electro-motive force and temperature for the rod free from magnetism (*i. e.*, without magnetizing current), included a single series of the same number of observations for the magnetized rod (*i. e.*, with current). The thermo-electric constants of the first and third series were therefore to be regarded as identical,

[109] Chap. II —36.

while those of the second would differ from them by an amount equivalent to the magnetic effect to be measured. In order that all direct action of the helix on the galvanometers or parts of the circuit might be avoided, the former with its attached thermo-element was placed at a great distance (100 feet) from the latter. These remote parts of the set of apparatus being connected by copper wire of a given kind, no discrepancies due to extraneous thermo-currents in the connections were to be apprehended. On all these points we satisfied ourselves by special tests.

*Results.*—(1) The results of the three series of observations in question are contained in the following table. If $e$ be the electro-motive force for the temperatures $t$ and $T$ of the junctions, we have

$$e=a(T-t)+b(T^2-t^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

a formula to be applied to the three cases. We proceeded as follows: Having calculated the constants $a$ and $b$ for the series of observations *I* and *III* (unmagnetic iron-copper) by the method of least squares, the mean of the two values of each was taken, and together with the temperatures $T$ and $t$ belonging to the series *II*, was used in deducing values of $e$ for this series, by the aid of formula (1). In the table the latter are given in parentheses. They are therefore such as would hold for the element unmagnetic copper-iron under circumstances identical with those in which the element magnetic copper-iron was actually placed.

TABLE 45.—*Thermo-electric power of magnetic and unmagnetic iron.*

| | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | |
|---|---|---|---|---|---|---|
| | °C. | °C. | *microvolts.* | *microvolts.* | | |
| I. Iron wire not magnetic[1] | 15.5 | 71.9 | 564.1 | 564.0 | +0.1 | $a=$ 11.869 |
| | 15.4 | 60.1 | 456.9 | 458.3 | −1.4 | $b=-$ 0.0213 |
| | 15.3 | 50.0 | 364.7 | 363.3 | +1.4 | |
| | 15.3 | 39.7 | 261.7 | 260.8 | +0.9 | |
| | 15.2 | 31.0 | 171.3 | 171.9 | −0.6 | |
| II. Iron wire magnetic | 15.1 | 83.6 | 674.2 | (669.3) | +4.9 | |
| | 15.0 | 72.5 | 578.8 | (575.5) | +3.3 | |
| | 15.0 | 58.2 | 448.9 | (445.5) | +3.4 | |
| | 15.0 | 46.2 | 332.5 | (329.6) | +2.9 | |
| | 14.9 | 35.9 | 229.5 | (226.5) | +3.0 | |
| III. Iron wire not magnetic | 14.8 | 90.8 | 733.8 | 732.3 | +1.5 | $a=$ 11.863 |
| | 14.8 | 79.3 | 635.9 | 637.2 | −1.3 | $b=-$ 0.0211 |
| | 14.8 | 67.8 | 536.2 | 536.3 | −0.1 | |
| | 14.7 | 54.0 | 408.8 | 409.2 | −0.4 | |
| | 14.7 | 45.0 | 325.7 | 325.2 | +0.5 | |

[1] Electro-motive force relatively to copper (given sample), as zero, in each of the three cases.

An inspection of the column of differences proves conclusively that longitudinally magnetic iron wire is thermo-electrically more positive than iron free from magnetism. We have, therefore, a corroboration of Thomson's result.

Nevertheless, the differences in question are small, and if we compare them with the set of values for the series I and III in the same column we infer that they must be largely distorted by incidental errors. It appears, therefore, that the observations are not adequately exact for

the calculation of the constants of the element magnetic-unmagnetic iron with the desirable accuracy, though they do furnish a good estimate of their value.

(2) For this reason we made a second set of experiments differing from the above in so far as much greater intervals ($T-t$) of temperature were chosen. $T$ and $t$ being kept as nearly constant as possible, measurements of $e$ for the magnetized and unmagnetized state of iron were alternately made. Supposing the resistances of Bosscha's zero method to have been so adjusted that for given values of $T$ and $t$ and unmagnetic iron no current was appreciable in the galvanometer, it was found that a permanent deflection at this instrument immediately occurred on closing the magnetizing circuit through the helix, of such a kind as to indicate an *increase* of thermo-electromotive force. That this effect is of purely thermo-electric origin, and is not to be directly ascribed to extraneous influences, follows conclusively from the regularity of increase of $e$ with increasing values of $T$. To produce different but temporarily constant values of the latter quantity the boiling point of water and of aniline and the melting point of lead were found serviceable.

The table below contains mean values of electro-motive force and temperature, the results being derived from a great number of measurements of $e$, with alternately open and closed magnetizing current, for each pair of values of $T$ and $t$. The differences between the values of $e$ corresponding to magnetic and unmagnetic iron respectively, enable us to calculate the constants $a$ and $b$ for the thermo-couple composed of two identical iron rods, one of which, however, is magnetically saturated, the other free from magnetism.

TABLE 46.—*Thermo-electric power of magnetic and unmagnetic iron.*

| | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | |
|---|---|---|---|---|---|---|
| | °C | °C | *microvolts.* | *microvolts.* | | |
| I. Iron wire, not magnetic[1] | 16.5 | 99.3 | 785 | 787 | −2 | $a=$ 12.49 |
| | 15.4 | 184.2 | 1256 | 1251 | +5 | $b=-$ 0.0240 |
| | 17. | 328. | 1173 | 1178 | −5 | |
| II. Iron wire, magnetic[1] | 16.5 | 99.2 | 788 | 790 | −2 | $a=$ 12.43 |
| | 15.4 | 184.2 | 1267 | 1261 | +6 | $b=-$ 0.0248 |
| | 17. | 328. | 1199 | 1204 | −5 | |
| Thermo-electric couple: magnetic-unmagnetic iron[2] | 16.5 | 99.2 | 4.0 | 4.2 | −0.2 | $a=+$ 0.035 |
| | 15.4 | 184.0 | 11.3 | 10.5 | +0.8 | $b=+$ 0.00014 |
| | 17. | 328. | 25.4 | 25.8 | −0.4 | |

[1] Thermo-electromotive force relatively to copper (given sample) as zero.
[2] Thermo-electromotive force relatively to unmagnetic iron as zero.

*Value of the effect.*—The thermo-electric effect of magnetization, as given by the constant $a$, is therefore +0.035. The corresponding effect due to tempering—*i. e.*, the difference between the constants $a$ for the soft and for the glass-hard state—attains values as high as 13.0. Hence,

even if the behavior of iron and steel were qualitatively the same—an unfavorable supposition not in accord with Thomson's observations—the increment of thermo-electric power resulting from complete saturation would only amount to a few tenths per cent. of the thermo-electric interval between soft and glass-hard steel. But in our experiments we shall have to do with permanent magnetism only, whence it follows that the discrepancy will be reduced to a much smaller value. We conclude that the thermo-electric hardness of a steel rod is practically *independent* of its magnetic state.

A remark on the general character of the strains met with in this chapter is in order here:

(1.) In the case of steel (cylindrical rods) hardened by tempering, we observe a dense external shell surrounding an abnormally rare core, in such a way that greatest intensity of stress is exerted in the radial direction; *i. e.*, at right angles to the axis of figure. Tempered steel has been shown to be thermo-electrically negative towards soft steel.

(2.) In the case of steel hardened by drawing through a wire-iron, we observe a compressed external shell (though of far lesser density than in the first case) surrounding a slightly rarified core, in such a way that greatest intensity of stress is exerted in an axial direction. Hard-drawn steel is thermo-electrically positive toward soft steel.[110]

(3.) If an iron wire is longitudinally stretched and the deformation temporary, then the strain, so far as its electrical indications are concerned, is similar to the magnetic strain in iron.

[110] Magnus: Pogg. Ann., LXXXIII, p. 469, 1851.

## CHAPTER V.

### ON THE INFLUENCE OF HARDNESS ON THE MAXIMUM OF MAGNETIZATION WHICH THIN CYLINDRICAL STEEL RODS OF DIFFERENT DIMENSIONS PERMANENTLY RETAIN.

### PLAN AND PURPOSE OF THE PRESENT EXPERIMENTS.

*Earlier results.*—The relation existing between the magnetic properties and the state of hardness of steel has been made the subject of a very large number of investigations.[111]

*Dimension-ratio and hardness.*—After the apparently discordant results of J. Müller, Plücker, and Wiedemann, on the one hand, and Hansteen and Lamont, on the other, had been interpreted by Ch. Ruths in a very thorough investigation—subsequently corroborated by Fromme—the present question may be said to have been answered in so far as the practically important factor, the ratio of dimensions of the material experimented upon, is concerned. It was herewith conclusively proven that both temporary[112] and permanent magnetism show a totally different kind of dependence on the state of hardness of steel when the saturated rods are long than when they are short. On the basis of these researches our knowledge of the practically more important permanent magnetism, more particularly the maximum possible for a given cylindrical steel rod, may be summarily stated as follows:

So long as the ratio of length to diameter is smaller than a certain

[111] Digests of the earlier papers may be found in J. Lamont, Handbuch des Magnetismus, p. 249, 1867; G. Wiedemann, Galvanismus, II *a*, p. 340, 1874. Among the more recent publications (since 1876) the following are especially to be mentioned: Ch. Ruths, Inaug. Dissertion, p. 34, Darmstadt, 1874; Ch. Ruths, Ueber den Magnetismus weicher Eisencylinder, etc., Dortmund, 1876; J. M. Gangain, Comptes Rend., LXXXII, p. 144, 1876; C. Fromme, Göttinger Nachrichten, p. 157, 1876; Trève et Durassier, Comptes Rend., LXXXII, p. 145, 1876; A. v. Waltenhofen, Dingler's Journal, CCXVII, p. 357, 1876; ibid., CCXXXII, p. 141, 1879; Gray, Phil. Mag. (5), VI, p. 321-332, 1878; A. Righi, Beiblätter, V, p. 62, 1881; W. Metcalf, Beiblätter, V, p. 895, 1881; A. Pictet, Arch. de Gen. (3), VI, p. 113-125, 1881.

The remarks made in this and the following chapters were originally published in the Verhandl. der phys.-med. ges. zu Würzburg," N. F. XVII, p. 19, 1882. The present paper differs from these in form, the observations having been reduced throughout to the current absolute electromagnetic units, and by containing a large number of experiments made since the date of original publication. It will be found that the latter have added essential corroboration to the inferences drawn. The reduction in question, presupposing a knowledge of the contents of Chapter I, has not until lately been feasible.

[112] The terms "permanent" and "temporary" as used here have the signification proposed by G. Wiedemann in Beiblätter I, p. 67, 1877.

limiting value, apparently characteristic of the material chosen, cylindrical rods are capable of retaining a greater intensity of magnetism permanently when in the glass-hard than when in the annealed state; but after the ratio in question increases to values above this limit, hard rods are overtaken in this respect by the yellow annealed; these in turn by the blue annealed. Soft rods, *cæteris paribus*, usually retain more magnetism than hard or annealed rods of the same dimensions, except when the ratio of axes is small.

*Carburation.*—The results in hand for the specific magnetic effect of carburation are even more unsatisfactory. We possess at best cursory or isolated data, due to Barlow,[113] Müller,[114] Jamin,[115] v. Waltenhofen,[116] Pictet.[117] To our knowledge the only attempt at a systematic research with reference to the effect of carburation was made by Trève and Durassier.[118] But the results of these observers are far from being even approximately complete. They are, moreover, seriously obscure, because insufficient attention is paid both to hardness and dimensions.

Taken as a whole, therefore, the work done, however valuable, can serve for orientation only. It is of the nature of a mere estimate. The full and minute analysis must introduce all those complications of a metallurgical kind which render the term "steel" itself indefinite. In this place the effect of carburation cannot even be discussed with advantage. It will, therefore, be waived, to be resumed in Chapter VII of the present memoir, where we shall have occasion to review the physical characteristics of the iron carburets in general.

*Critical discussion.*—Returning from this digression to a discussion of the magnetic effect of the hardness and of the dimensions of steel rods, we find it undeniable, although the main features of the subject may be said to be roughly outlined, that the information gained is almost intangibly vague and unsatisfactory. In fact, the solution is at most a qualitative one. The data of the above researches, in other words, do not enable us to trace the continuous change of magnetic intensity of thin saturated steel rods, considered for the time being as a function of a single independent variable hardness only—the steel passing from an initial (soft) to a final (hard) state through every intermediate state, dimensions and carburation being regarded as parameters. And yet it is only from results of this character that an intelligent insight into these complicated phenomena can be obtained.

There are two difficulties which have thus far stood in the way of more exact research in this direction. The first of these was the want of a sufficiently sensitive method for the discrimination between degrees of

[113] Barlow: Phil. Trans. p. 117, 1822.
[114] Müller: Pogg. Ann., LXXXV, p. 157, 1852.
[115] Jamin: Comptes Rend., LXXVII, p. 89, 1873.
[116] V. Waltenhofen: Pogg. Ann., CXXI, p. 431, 1864.
[117] Pictet: Arch. de Genève (3), VI, p. 113, 1881.
[118] Trève et Durassier, Mondes, XXVIII, pp. 587, 667, 1875.

hardness. The estimate furnished by the oxide tints,[119] if indeed rigidly reliable, is much too crude. The same would be true of any other of the more current methods. After we had found, therefore, how well the electrical properties of steel can be thus utilized—after we had seen, for instance, that the annealing effect of temperature as low as 50° C. can be pursued and studied with the utmost nicety—the application of our method to magnetic phenomena at once forcibly presented itself. Subsequently certain analogies, which appear to exist between hardness itself when measured electrically and permanent magnetic moment, rendered the application of our method even more desirable. With regard to the second difficulty, we want in this place again to emphasize that the behavior of rods of different dimensions cannot by any means be immediately compared unless, *cæteris paribus*, the same thickness occurs throughout. Most of the observers cited, however, have obtained their results with rods for which different values of $L : D$ were secured[120] by retaining $L$ constant and varying $D$. Now, it is, *a priori*, to be anticipated that glass-hardening, accompanied or not by subsequent annealing, will be productive of different effects, of states of hardness, which, even if temperature and time are identical, are structurally[121] the more dissimilar in proportion as the rods subjected to these operations differ in diameter. Nor is this all. Difference of thickness usually implies a difference in chemical composition, unless, indeed, the specimens chosen are cut from the same piece of steel. To our knowledge, in none of the above researches (rods from 0.2 centimeter to 0.7 centimeter in diameter) was this done. How very different the behavior of rods frequently is, even when coming from the same source and nominally of the same kind of steel, will appear from several examples to be cited in the next paragraph.

Thomson's law, in accordance with which geometrically similar rods show equal moments per unit of mass when placed in identical magnetic fields, is probably true for iron, but cannot be immediately applied to the case of steel: possibly it may be applied to very soft rods; to a lesser extent to those in the annealed state; certainly not to glass-hard rods, inasmuch as here the peculiarities of internal structure resulting from the process of tempering manifest themselves, even in the case of

[119] It is highly probable that a given oxide tint can be obtained in an infinite number of ways by varying temperature and time of exposure simultaneously: lower temperatures acting for very long intervals of time producing the same color effect as higher temperatures for short periods of exposure. Researches on this subject are in progress. Possibly the variation of color may correspond very closely with the actual variation of hardness, as discussed in Chapter II.

[120] All the above remarks apply to cylindrical rods of length $L$ and diameter $D$.

[121] Structure, as used here and elsewhere, refers to the variation of density encountered on passing along a radius from the axis of the rod to the circumference. In how far the structure of rods of different diameters will vary cannot even be conjectured.

geometrically similar figures, in a way that compels us to treat each thickness individually.[122]

*The present experiments.*—The above remarks, we believe, clearly show that the whole of our knowledge on the relation of magnetism to the variables, carburation, hardness, and dimensions, is urgently in need not only of reconstruction, but of further elucidation; and we took great delight in welcoming this opportunity for the practical application of the experience which the attention of many years to the physical properties of steel has given us. The first part of our projected magnetic researches, referring principally to long, thin rods, to annealing temperatures below 500° C., and to the soft state, are herewith made public. The second part, on the behavior of short, thick rods, and on the influence of temperatures between 400° and 1,000°, will have to be reserved for another communication. We may add, more specifically, that for the 30 rods examined in the present experiments the ratio of dimensions, $\alpha = \frac{L}{D}$, varied between $\alpha = 120$ and $\alpha = 10$. But the data in this chapter enable us to predict the magnetic behavior, even for magnets in which the said ratio ($\alpha$) lies below 10 or above 120, with a degree of probability amounting almost to certainty. But, in view of the importance of thick magnets, now so largely used in magnetometric and galvanometric work, a new research on this subject seems pertinent. Similar remarks apply to high annealing temperatures.

We conclude this paragraph with the appropriate remark that our knowledge of the excessively complicated phenomena under consideration can be advanced by tentative methods alone. The mathematical theory of the subject, even in case of homogeneous material, encounters formidable and almost insuperable difficulties. But we will be able to show in the sequel that the condition of internal structure is one of the most essential factors which determine the magnetic character of the (tempered) rod. Again, the investigation of the true nature of the structural properties of hard steel is surrounded with difficulties which will long baffle the experimentalist's skill. For in all such methods, like the one which Fromme pursued in order to obtain preliminary data on the condition of the interior of a steel rod, and in which the external layers are gradually and consecutively removed by acids or otherwise, we apprehend that the rod, for the very reason of this removal, will change its physical condition (strain) while in the hands of the operator. Long before we reach the core of the rod its density and electrical properties must be conceded to have changed materially. Nevertheless, we infer that the structure of tempered steel is of a thoroughly definite and distinct character; that this is emphatically

[122] This inference, which we published in the same form in 1882, has since been corroborated by H. Meyer, in his paper "Ueber die Magnetisirungsfunction von Stahl u. Nickel," Wied. Ann., XVIII, p. 248, 1883. Meyer contends that Thomson's law is true neither for soft nor for hard steel rods.

demonstrated by beautiful consistency and uniformity of our different series of results, obtained with different steel rods, tempered at different times.

## ON THE MATERIAL USED.

*The steel.*—The steel chosen was that described in the previous chapter. It was received in the shape of rods 30 centimeters long and from 0.084 centimeter to 0.150 centimeter in diameter. These were hardened as shown above (Chap. II, pp. 29–31). Analyses are superfluous, as it is our intention at present to study the results for a single value of the variable parameter, carburation, only; or, in other words, to investigate the magnetic behavior of a given type of steel. From the large supply of tempered rods such were chosen as not only showed a maximum of thermo-electric hardness for the glass-hard state, but also, when tested for longitudinal homogeneity in the manner described in pages 38, 121, gave the most satisfactory results.

*Rods of like composition, thickness, temper.*—At the outstart we were inclined to infer that from rods of the same kind of steel (composition), of the same thickness, and tempered in the same manner—in so far as the details of this process are at the observer's control—comparable values of the maximum of magnetic intensity could be immediately derived. For the purpose of testing this supposition, rods of nearly the same thermo-electric hardness (II, p. 65), but of different lengths, were broken from different samples of the class of rods experimented upon. These, after having been subjected alike to the action of the same magnetic field—in our case of unnecessarily great intensity and fairly uniform—according to Thomson's law ought to have retained a moment per unit of mass such as would be expressible by the same function of the ratio of length to diameter. Moreover, as the thickness of the rods chosen was practically the same, this function would have to increase to a certain limiting value, as the corresponding lengths increased from zero indefinitely.

These anticipations were, however, by no means realized. In this place it will be well to add, by way of example, such results as are particularly applicable for the illustration of the consideration just made:

A magnet 4.1 centimeters long, 0.084 centimeter thick, weighing 0.173 gram, specific resistance $s=39.8$ at 17.6 degrees, after saturation was found to have the specific magnetism $m=43.0$; whereas another specimen taken from a different rod, the magnet being only 3.05 centimeters long, 0.084 centimeter thick, weighing 0.131 gram, specific resistance $s=39.4$ at 18.5 degrees, after saturation had retained $m=52.0$; whence it appears that in the second case, notwithstanding the fact that the length (or ratio of dimensions) was only about three-fourths of that

in the first, a very decidedly greater intensity of magnetization was attainable. This is hardly referable to a difference of composition. In all probability the result is to be associated with peculiarities of the internal structure of the rods.

The following example is still more to the point:

A magnet (*a*) 5.0 centimeters long, 0.084 centimeter thick, weighing 0.214 gram, of the specific resistance $s=40.4$ at 18.5 degrees, had retained the specific magnetism $m=45.8$; another taken from a second rod of the same thickness, the magnet (*b*) being 5.9 centimeters long, as before 0.084 centimeter thick, weighing 0.249 gram, of the specific resistance $s=39.7$ at 18.3 degrees, gave, after saturation, $m=45.0$.

In order to arrive at some inference as to the cause of this difference of magnetic state, both the magnets last mentioned were slowly annealed, at first for a period of ten hours in steam, thereupon for an additional period of ten hours in aniline vapor at 185 degrees, finally for one hour in melted lead at 330 degrees. After this both were softened by heating to redness and cooling slowly. For each of the particular states of hardness thus obtained the specific resistance was measured. The rods were then magnetized to saturation and their magnetic moment determined. The results of these precursory experiments are given in the following table:

| | (*a*) | | | (*b*) | | |
|---|---|---|---|---|---|---|
| | *s* | *t* | *m* | *s* | *t* | *m* |
| Glass-hard | 40.6 | 18 | 45.8 | 39.9 | 18 | 45.0 |
| 10h in 100° | 35.2 | 20 | 43.1 | 35.1 | 20 | 42.7 |
| 10h in 185° | 26.6 | 20 | 62.2 | 26.4 | 20 | 61.7 |
| 1h in 330° | 20.3 | 20 | 84.3 | 20.1 | 20 | 85.0 |
| Soft | 16.9 | 20 | 46.8 | 16.7 | 20 | 56.0 |

From an inspection of the table, or of Fig. 15, it is obvious that at 330° (lead bath) the magnetic intensity of the longer magnet (*b*) has overtaken that of (*a*), but it is not until both magnets are quite soft (homogeneous) that the normal behavior fully appears. It is to be noted, however, that this experiment is not in itself perfectly conclusive. The influence of carburation is principally efficient in the glass-hard state; $L:D$, if its value be as large as in the present case, less so. In the soft state, however, the effect of $L:D$ predominates. It would be possible, therefore, with due consideration of the values of *s*, to ascribe the results obtained to a difference of carburation between (*a*) and (*b*). The nearly equal values of specific resistance for the soft state, especially when viewed in the additional light given by the first example, make the latter inference improbable.

*Each series of magnets originally integrant parts of the same hard rod.*— The individuality of behavior of different rods (*i. e.*, such as are not

pieces of the same homogeneous rod, though otherwise identical) appears, therefore, to be conclusively demonstrated.[123]

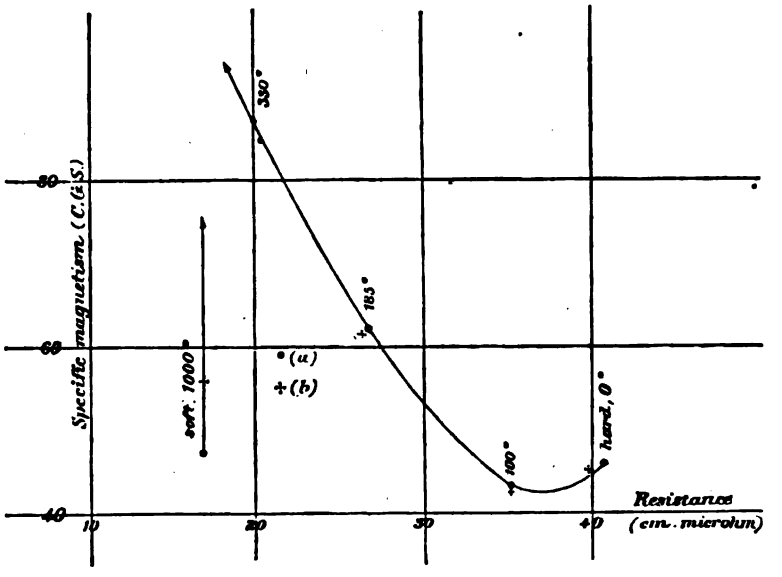



FIG. 15.—Specific magnetism of rods annealed from 0° to 1000°.

Results of this kind—a number of other examples might be cited—urged the inference upon us that only in the case where magnets are broken from one and the same longitudinally homogeneous hard rod, can comparable and harmonious results be expected. Add to this the fact that the frequent reheatings to redness, necessary in drawing a wire to small diameter, imply a difference of carburation in different samples, for this reason alone. However insignificant this may appear to be, we were convinced that its effect, where accurate results are called for, is by no means negligible. These instances are adequate to give emphasis to the statement above made, that each rod must be examined and treated separately. Indeed, a better opinion of the longitudinal homogeneity of a wire can be formed subsequently from an inspection of the behavior of the different magnets taken out of it, than could be formed at the outset by the aid of the electrical properties of different parts of the rod in question.

Unfortunately, thin (diameter $= 2\rho = 0.084$ centimeter) glass-hard rods, of the same hardness throughout their length, out of which magnets of the kind desired, having different values for the ratio of dimension ($L : D$), can be broken, are only obtainable with great difficulty.

[123] It is quite clear that even the details of the process of tempering have an important bearing on the magnetic intensity of hard rods. A single rod repeatedly rehardened shows very marked differences in the maximum of permanent magnetization for nominally the same state.

form. The samples selected from our supply showed differences of trical conductivity for different parts of their lengths, amounting to a few tenths of one per cent.

## METHOD OF MAGNETIZATION.

*Helix. Magnetic field.*—Magnetization was effected by the indu action of a galvanic current in a helix. As a source of current Hefner-Alteneck dynamo-electric machine of the Physical Institu Würzburg was at our disposal. A magnetic field of very great inte could thus easily be produced, and discrepancies due to non-satur were therefore not to be apprehended.

The helix referred to (length $2a=22.3$ centimeters, inner radius $r$ centimeters, outer radius $r=5.3$ centimeters) contained ten laye each of which there were $n=55$ turns of thick copper wire.

If a current, $i$, circulates through the helix, the magnetizing forc at a point on its axis at a distance $b$ from its center will be

$$X_b=\frac{\pi ni}{a}\left[\frac{a+b}{\sqrt{(a+b)^2+r^2}}+\frac{a-b}{\sqrt{(a-b)^2+r^2}}\right]$$

In our case the mean value of current was

$$i=3.0\,\frac{g^{\frac{1}{2}}\,cm^{\frac{1}{2}}}{sec}=30 \text{ Ampères}$$

If this value is introduced into the formula specified and the ag gate of the value of $X_b$ calculated, the total intensity $\Sigma X_b$ of the n netic field at different points $b$ (cm) on the axis varied as follows:

| $b=$ | 0 | 1 | 2 | 3 | 4 | 5 | (cm) |
|---|---|---|---|---|---|---|---|

usual case of magnets of lesser length much smaller variations present themselves. On the other hand, where permanent magnetism is alone of interest and the field of great intensity, the desideratum of uniformity is perhaps of minor importance.

The mean intensity $X$ of the magnetizing force due to a single layer of wire and corresponding to a length $2b$ (cm) symmetrically located with respect to the center of the helix is

$$X=\frac{\pi ni}{ab}\left[\sqrt{(a+b)^2+r^2}-\sqrt{(a-b)^2+r^2}\right]$$

In the present case the aggregate $\Sigma X$ of these means, or the mean intensity of the field due to the whole helix, corresponding to the part $2b$ of the axis situated as specified was

| $b=$ | 0 | 1 | 2 | 3 | 4 | 5 | (cm) |
|---|---|---|---|---|---|---|---|
| $\Sigma X=$ | 884 | 883 | 882 | 880 | 877 | 874 | $\frac{g^{\frac{1}{2}}}{cm^{\frac{1}{2}}\,sec}$ |

The largest values of $\Sigma X$ employed by Ruths, for instance, in his researches on temporary magnetism, were $\Sigma X=40$ for iron and $\Sigma X=147$ for steel. There can be no doubt, therefore, that in our case the most complete saturation possible was actually attained. Indeed, we had frequent occasion to convince ourselves that successive magnetization produced no additional effect equivalent to one per cent. of the whole moment.

*Magnetization.*—In the case where magnetism is induced by means of a helix, the question in reference to the manner in which the magnets are to be introduced and withdrawn from its action is always of importance. Some observers, among them J. Wiedemann and C. Fromme, placed their magnets in the helix after the current had been closed and withdrew them before breaking it. In this way the complications due to certain undesirable induced currents are avoided. At the same time, however, the advantages of a uniform field are lost and a normal distribution of magnetism possibly interfered with. For the last mentioned reasons, Holz and Fromme preferred to open and close the current while the rod to be magnetized lay in place. Both methods have been made the subject of an experimental comparison by Fromme.[124]

We gave preference to neither of these methods, but chose a plan which, under the circumstances, was also the most convenient. It consisted in allowing the current to increase from zero to its maximum value gradually and then again to wane in the same manner. This may be satisfactorily accomplished by appropriately applying the power to the dynamo-electric machine. We think we are justified in the belief that in this way the permanent magnetic moment is finally weakened only to a negligible extent, at least to a smaller amount than in either of the other methods.

[124] C. Fromme, Wied. Ann., V, p. 345, 1878.

*Apparatus.*—The magnetic moments of the wires were derived f
the deflection of a small magnetized steel mirror, observed after
manner of Poggendorf with telescope and scale. We made use o
appliance due to Professor Kohlrausch, by means of which the atta
magnets could always again be brought into the same position relati
to the mirror, and rotated 180° around the vertical. Both the first
the second method of Gauss were applied.

The apparatus consisted of a solid brass ring provided with lev
screws, from which two vertical columns of the same metal arose
porting a circle graduated in degrees. An alhidade, with two
niers, resting on conical bearings, occupied a central position within
latter. A horizontal brass bar, in connection with the middle of
alhidade, and adjustable with reference to the vertical, carried o
lower edge the special device above referred to, by the aid of w
the magnets were appropriately fastened in position. This appa
was fixed in place and adjusted at the outset, and the distance
tween the axis and that of the needle determined once for all. In
way the relative values of the moments of our magnets (and it is
these that the results of the present paper are principally deduced
independent of discrepancies introduced by errors in the determin
of the distance between magnet and mirror.

*Method.*—In calculating the results we made use of the ordi
formulæ

$$M=\tfrac{1}{2}\frac{r^3\,T\,\text{tang}\,\varphi}{1+\tfrac{1}{2}\frac{l^2}{r^2}}$$

for the first, and

$$M=\frac{r^3\,T\,\text{tang}\,\varphi}{1-\tfrac{3}{8}\frac{l^2}{r^2}}$$

flection, $l$ the distance between the poles. We assumed $l=0.85\,L$ where $L$ is the length of the magnet. This approximation is sufficient because the term of the above formulæ involving $l$ is only of the nature of a correction.

The measurements were made at ordinary temperatures, varying between 18° and 21°. The effects of the changes in the magnetic moment, as well as those due to variation of terrestrial magnetism, we regarded negligible. This is also true with reference to the torsional discrepancy of the silk fiber (the torsion-coefficient was found to be only 0.00032).

In addition to the magnetic moment $M$ of the whole rod we shall give throughout the moment $m$ per unit of mass (1 g.). To this quantity the name *specific magnetism* has been given. In the case where a number of different magnets are compared it is a more perspicuous result than the former.

## DETERMINATION OF THE DEGREE OF HARDNESS.

*Resistance measurement.*—Of the two methods of estimating the hardness of the rods proposed in Chapter II, one of which depends upon thermo-electric properties, the other upon the specific resistance of steel, we chose the latter because of its greater simplicity. Here again it was our object, primarily, to arrive at accurate relative values, and this we were able to accomplish satisfactorily by the aid of Matthiessen and Hockin's modification of the bridge. In one of the branches of Wheatstone's combination, the bridge cylinder of F. Kohlrausch (diagramatically represented in Fig. 16 by the straight line $AB$) was inserted; in the other the steel wire $D_1D_2$, whose resistance is to be measured, and a tenth Siemens unit $Z_3Z_4$, the whole being appropriately connected with thick copper wire. Flat clamp-screws of brass pressed the steel rod down firmly upon a plane surface. In this way the danger of breaking the very brittle magnets was less seriously to be apprehended. The normal $Z_3Z_4$ was made of heavy German silver wire soldered to thick terminals. These were amalgamated and in galvanic connection with the bridge by means of mercury. From the points $A$ and $B$ the copper-connecting wires lead to a galvanometer, the deflections of which are observed with telescope and scale. As a source of current two Smee elements were found sufficient.

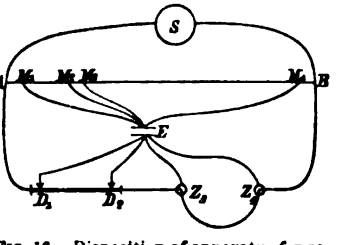


FIG. 16.—Disposition of apparatus for resistance measurement.

In figure 16, if the points $D_1$, $D_2$, $Z_3$, $Z_4$ correspond to the points $M_1$, $M_2$, $M_3$, $M_4$, in such a way that when connected respectively with the

terminal of the battery, the current in the galvanometer ($S$) is zero, we have

$$\frac{D_1, D_2}{Z_3, Z_4} = \frac{M_1, M_2}{M_3, M_4}$$

To obtain the points of contact $D_1$ and $D_2$, we made use of two steel needles, the points of which had been flattened wedge-shaped. These were fastened parallel to each other, and at a fixed distance apart, in a small piece of wood. To their tops the ends of two long thin copper wires were soldered. This arrangement, after having been screwed to a longer Γ-shaped piece of wood, along which the copper wires were led, represented as a whole a kind of tripod, two of the feet being the steel needles mentioned. During the measurements the latter stood on the steel rod to be tested. Small clamp-screws served for connecting the battery-wires with the terminals of this apparatus, these being sufficiently long and thin that the successive clamping and unclamping did not interfere with the adjustment in such a way as to slide the points $D_1$, $D_2$ along the steel rod, for instance.

This simple contrivance, which is easily improvised, gave us results of the most satisfactory kind. Our resistances were rarely larger than a few hundredths ohm. Nevertheless they were determinable with an accuracy of a few tenths per cent. with certainty. Our mirror-galvanometer enabled us to adjust the sliding contact on the bridge-cylinder of Kohlrausch to $\frac{1}{10}$ a scale-part, or $\frac{1}{10000}$ of the length of the wire $A$, $B$. In virtue of a fixed distance $D_1$, $D_2$—we possessed a number of these arrangements to be used according as a larger or a smaller wire was to be operated upon—in view of the stability of the apparatus as a whole, and of the fact that all operations were conducted in a room of practically constant temperature, an unusual accuracy in the relative data was attained.

It is obvious that this method is applicable at once as a test for the degree of uniformity of hardness along the length of the wire. By placing the contrivance just described on different consecutive lengths without making any further alteration in the adjustments, the respective resistances of these parts could be subjected to a minute comparison. This furnishes us with the criterion desired.

Great difficulties were encountered in the measurement of the sections of the steel wires. We determined the diameter microscopically, with the aid of an ocular micrometer of known factor. Two readings, corresponding to diameters at right angles to each other, each pair taken at a number of different, approximately equidistant parts of the wires were made. The mean of these individual values was accepted. This plan was fairly good in so far as the error made in the measurement of the sections does not influence the relative values of resistance.

From the observed resistance of any wire at $t$ degrees, the value of this quantity per meter, in ohms ($w$), was calculated. A knowledge of the tem

perature-coefficients of steel[126] then enabled us to deduce herefrom the specific resistance (resistance in microhms between opposite faces of a cubic centimeter) for the temperature 0°. This value, $s\left(\frac{cm}{cm^3}\ 0°\ \text{microhm}\right)$, has been adopted as a measure of hardness.

From $s$, the thermo-electric hardness of our wires may be calculated by the aid of the formula

$$h = 0.412\ s$$

In this way the present scale of hardness is made identical with that previously employed in our work on the phenomena of annealing. The data $h$ are therefore proportional to the specific resistances of the steel rods and have a very simple connection with the respective thermo-electric constants $a$, as has been shown elsewhere.[127]

## METHOD OF ANNEALING.

*Systematic plan.*—In the different series of experiments the glass-hard state was chosen as the point of departure. After the rods had been examined with reference to their hardness in the way described, they were magnetized to saturation and their magnetic moment determined. Thereupon we exposed them to the annealing effect of steam at 100°. A sufficiently small decrement of hardness resulted by continuing the operation for one hour at first, and then for additional two, three, and four hours, amounting in the aggregate to ten hours of exposure. This is sufficient to bring the rod as near the limiting state, or the maximum of permanent hardness corresponding to 100° as is easily practicable.

The magnets were now subjected to the action of aniline vapor at 185°, during successive intervals of twenty minutes, forty minutes, two, four, and finally six hours.

A lead bath at 330° was next chosen. At first the magnets were annealed therein for a time of one minute only. Then the action was prolonged to one hour. In the later experiments the melting point of tin (240°) as well as that of zinc (420°) were found serviceable as temperatures of annealing.

Finally the rods were thoroughly softened in the usual way, by heating to redness and cooling very slowly. To avoid oxidation of the magnets we imbedded them in pulverized artificial ferro-ferric oxide, surrounded this with fire-clay, and finally enveloped the whole with a piece of gas-pipe.

In this way we obtained about twelve distinct states of hardness, distributed with fair uniformity between the glass hard and soft states, as

[126] Cf. Chapter I. [127] Chapter II, p. 63.

extremes. It is only between the soft condition and that corresponding to the temperature 300° of the annealing bath that a greater number of degrees of hardness, as our results eventually showed, would have been desirable. Particularly in the case of long magnets there appear within this interval changes of magnetic capacity of a very significant character, changes, moreover, which cannot be satisfactorily supplied by a process of interpolation based on the data for neighboring states.

After the magnets had been taken out of the annealing bath it was our custom to put them aside for some time in order to allow a complete cessation of possible "after" effects. Thereupon the test for hardness was applied.

*Results of the annealing.*—The progress of annealing in the different experiments is fully given in the following tables:

TABLE 47.—*Thin wire.*

[$2\rho$=0.084 centimeter.]

| Description of temper. | Specific resistance $\frac{cm}{cm^2}$ 0° microhm. | |
|---|---|---|
| | Rod I. | Rod II. |
| Glass-hard | 38.5 | 37.3 |
| Annealed 1 hour in steam at 100° | 36.3 | 34.7 |
| Annealed 3 hours in steam at 100° | 34.8 | 33.0 |
| Annealed 6 hours in steam at 100° | 33.9 | 32.2 |
| Annealed 10 hours in steam at 100° | 33.4 | 31.6 |
| Annealed 20 minutes in aniline vapor at 185° | 29.5 | 27.4 |
| Annealed 1 hour in aniline vapor at 185° | 28.4 | 26.3 |
| Annealed 3 hours in aniline vapor at 185° | 27.1 | 24.9 |
| Annealed 7 hours in aniline vapor at 185° | 25.9 | 23.7 |
| Annealed 13 hours in aniline vapor at 185° | 25.0 | 22.8 |
| Annealed 1 minute in melting lead at 330° | 20.4 | 18.9 |
| Annealed 1 hour in melting lead at 330° | 18.8 | 17.4 |
| Annealed at red heat (soft) | 15.7 | 14.5 |

TABLE 48.—*Thick wire.*

[$2\rho$=0.15 centimeter.]

| Description of temper. | Specific resistance $\frac{cm}{cm^2}$ 0° microhm. | | | |
|---|---|---|---|---|
| | Rod IX. | Rod X | Rod XI. | Rod XII. |
| Glass-hard | 47.2 | 46.8 | 43.8 | 43.5 |
| Annealed 1 hour in steam at 100° | 42.0 | 41.7 | 38.6 | 38.4 |
| Annealed 3 hours in steam at 100° | 39.5 | 39.3 | 36.5 | 36.2 |
| Annealed 6 hours in steam at 100° | 38.2 | 38.0 | 35.1 | 34.9 |
| Annealed 10 hours in steam at 100° | 37.4 | 37.1 | 34.3 | 34.0 |
| Annealed 20 minutes in aniline vapor at 185° | 31.5 | 31.4 | 29.0 | 28.7 |
| Annealed 1 hour in aniline vapor at 185° | 29.7 | 29.6 | 27.5 | 27.3 |
| Annealed 3 hours in aniline vapor at 185° | 27.9 | 27.7 | 25.6 | 25.5 |
| Annealed 7 hours in aniline vapor at 185° | 26.2 | 26.0 | 24.2 | 24.9 |
| Annealed 13 hours in aniline vapor at 185° | 24.8 | 24.6 | 22.9 | 22.7 |
| Annealed 10 minutes in melting tin at 246° | 24.0 | 23.8 | 22.2 | 22.0 |
| Annealed 1 minute in melting lead at 330° | 20.3 | 20.1 | 19.0 | 18.7 |
| Annealed 1 hour in melting zinc at 420° | 17.5 | 17.2 | 16.2 | 16.0 |
| Annealed at red heat (soft) | 15.7 | 15.6 | 14.9 | 14.9 |

In how far we are justified in regarding the scale of hardness for rods in the magnetized state as *cæteris paribus* identical with the scale corresponding to the unmagnetized state has been fully discussed in the previous chapter on the thermo-electric effect of magnetization.[128]

## MAGNETIC RESULTS FOR RODS OF LARGE DIMENSION-RATIO.

*Description of magnets.*—The results of the experiments, the plan of which has been fully detailed in the preceding paragraphs, are given in the following tables.

The first experiments were made with wire of smaller diameter. Breaking rod No. I into three parts, we obtained the magnets Nos. 1, 2, 3; and, similarly, the magnets Nos. 6, 9, 10, from rod No. II. Accidentally, the longest of these, No. 10, during the course of the experiments, was further broken into parts, which, however, in their turn, were available for magnets. Nos. 5, 7, 8 were thus obtained. All magnets are numbered in the order of their respective lengths. The following table (49) contains certain important physical constants of the ten rods. We measured their dimensions first while they were in the glass-hard state; then after the various stages of annealing; finally, before and after thorough annealing at red heat. In this way we were able to arrive at numerical data for the simultaneous volume-contraction with some accuracy. Mean values are given in the tables. In calculating the specific gravity, $\Delta$, from the mass and dimensions of the individual rods, our main object was that of checking the measurement. In view of the small diameter, $\Delta$ will not be correct within 1 per cent.

TABLE 49.—*Constants of magnets.*

| Rod $2\rho$ cm, $\Delta$ | Magnet No. | Mass $\mu$ | Length $L$ | Dim. ratio. $a$ |
|---|---|---|---|---|
| | | *g* | *cm.* | |
| I. $2\rho=0.0838$ cm. $\Delta=7.70$ | 1 | 0.086 | 2.00 | 23.9 |
| | 2 | 172 | 4.05 | 48.4 |
| | 3 | 249 | 5.85 | 69.8 |
| | 4 | 336 | 7.90 | 94.3 |
| II. $2\rho=0.0831$ cm. $\Delta=7.69$ | 5 | 068 | 1.63 | 19.6 |
| | 6 | 126 | 3.03 | 36.5 |
| | 7 | 197 | 4.72 | 56.8 |
| | 8 | 236 | 5.66 | 68.1 |
| | 9 | 413 | 9.92 | 119.5 |
| | 10 | 502 | 12.06 | 145.1 |

The degree of homogeneity of these rods may be satisfactorily inferred from the data for $s$. In the case of Nos. 1, 5, 6, the method for the measurement of resistance could not readily be applied, the rods being too short. We, therefore, preferred to accept in place of such direct

[128] Wied. Ann., XIV, p. 54, 1881. Cf. W. Beetz, Pogg. Ann., CXXVIII, p. 193, 1866.

results, the values deducible by interpolation from those obtained from rods of like origin. Data of this kind are, however, distinguished in the next table by an asterisk (*) preceding the numbers.

*Magnetic data.*—The magnetic measurements were made in the second position of Gauss. The numerical values of the constants occurring in the formulæ—

$$m=\frac{M}{\mu} \qquad M=\frac{r^3 T \operatorname{tg}\varphi}{1-\frac{2}{3}\frac{r^3}{l^3}} \qquad 2\operatorname{tg}2\varphi=\frac{n}{R}$$

are as follows:

$$T=0.196\ \frac{\text{cm}^{\frac{1}{2}}\text{g}^{\frac{1}{2}}}{\text{sec}} \qquad r=26.34\text{ cm} \qquad R=207.4\text{ cm}$$

The results of the magnetic measurements are these:

TABLE 50.—*Relation between the magnetic constants of steel and hardness.*

1. *Magnets in the glass-hard state.*

| Rod. | Magnet No. | a | W 1 m | t | $s\frac{\text{cm}}{\text{cm}^2}\,\varphi^0$ | n | M | m |
|---|---|---|---|---|---|---|---|---|
| | | | ohm. | °C. | microhm. | cm. | abs. E. | abs. E. |
| I... | 1 | 24 | *0.726 | *18.2 | *38.5 | 1.34 | 2.89 | 32.7 |
| | 2 | 48 | 0.734 | 17.6 | 38.8 | 3.46 | 7.41 | 43.0 |
| | 3 | 70 | 0.727 | 18.3 | 38.6 | 5.28 | 11.20 | 45.0 |
| | 4 | 94 | 0.716 | 18.7 | 38.1 | 7.68 | 16.06 | 47.9 |
| II... | 6 | 36 | *0.719 | *18.5 | *37.3 | 2.58 | 5.54 | 42.9 |
| | 9 | 120 | 0.723 | 18.5 | 37.5 | 10.77 | 22.11 | 52.5 |
| | 10 | 145 | 0.714 | 18.5 | 37.1 | 13.78 | 27.65 | 55.1 |

2. *Magnets annealed 1 hour in steam.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I... | 1 | 24 | *0.687 | *18.4 | *36.3 | 1.33 | 2.85 | 31.3 |
| | 2 | 48 | 0.695 | 18.2 | 36.7 | 3.38 | 7.23 | 42.6 |
| | 3 | 70 | 0.688 | 18.4 | 36.4 | 5.19 | 11.01 | 44.3 |
| | 4 | 94 | 0.679 | 18.6 | 35.9 | 7.51 | 15.70 | 46.8 |
| II... | 6 | 36 | *0.670 | *18.6 | *34.7 | 2.53 | 5.44 | 42.1 |
| | 9 | 120 | 0.673 | 18.6 | 34.8 | 10.61 | 21.78 | 52.6 |
| | 10 | 145 | 0.667 | 18.6 | 34.6 | 13.53 | 27.15 | 54.1 |

3. *Magnets annealed 3 hours in steam.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I... | 1 | 24 | *0.662 | *20.1 | *34.8 | 1.30 | 2.80 | 32.7 |
| | 2 | 48 | 0.669 | 20.0 | 35.1 | 3.30 | 7.06 | 41.6 |
| | 3 | 70 | 0.665 | 20.2 | 34.9 | 5.08 | 10.78 | 43.3 |
| | 4 | 94 | 0.653 | 20.2 | 34.4 | 7.41 | 15.49 | 46.2 |
| II... | 6 | 36 | *0.641 | *20.1 | *33.0 | 2.50 | 5.36 | 42.5 |
| | 9 | 120 | 0.644 | 20.2 | 33.2 | 10.41 | 21.38 | 51.8 |
| | 10 | 145 | 0.638 | 20.1 | 32.9 | 13.29 | 26.67 | 53.2 |

4. *Magnets annealed 6 hours in steam.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I... | 1 | 24 | *0.648 | *21.1 | *33.9 | 1.28 | 2.76 | 32.2 |
| | 2 | 48 | 0.654 | 20.9 | 34.2 | 3.23 | 6.91 | 40.1 |
| | 3 | 70 | 0.651 | 21.3 | 34.1 | 5.00 | 10.60 | 42.7 |
| | 4 | 94 | 0.638 | 21.2 | 33.5 | 7.29 | 15.24 | 45.4 |
| II... | 6 | 36 | *0.626 | *21.0 | *32.2 | 2.47 | 5.31 | 42.0 |
| | 9 | 120 | 0.630 | 21.0 | 32.3 | 10.22 | 20.98 | 50.8 |
| | 10 | 145 | 0.623 | 21.0 | 32.1 | 13.05 | 26.19 | 52.2 |

TABLE 50.—*Relations between the magnetic constants of steel and hardness*—Continued.

5. *Magnets annealed 10 hours in steam.*

| Rod. | Magnet No. | $a$ | $W$ 1 m | $t$ | $s\frac{cm}{cm^3}0°$ | $n$ | $M$ | $m$ |
|---|---|---|---|---|---|---|---|---|
| | | | ohm. | °C. | microhm. | cm. | abs. E. | abs. E. |
| I. | 1 | 24 | *0.637 | *20.1 | *33.4 | 1.28 | 2.75 | 32.1 |
| | 2 | 48 | 0.645 | 20.2 | 33.7 | 3.24 | 6.93 | 40.2 |
| | 3 | 70 | 0.640 | 20.1 | 33.6 | 5.00 | 10.60 | 42.7 |
| | 4 | 94 | 0.627 | 20.0 | 33.0 | 7.30 | 15.25 | 45.4 |
| II. | 5 | 20 | *0.614 | *20.1 | *31.6 | 0.93 | 2.01 | 29.6 |
| | 6 | 36 | *0.614 | *20.1 | *31.6 | 2.42 | 5.19 | 41.1 |
| | 7 | 57 | 0.614 | 20.2 | 31.6 | 4.28 | 9.13 | 46.4 |
| | 8 | 68 | 0.612 | 20.3 | 31.4 | 5.30 | 11.20 | 47.8 |
| | 9 | 120 | 0.617 | 19.8 | 31.7 | 10.26 | 21.06 | 51.0 |

6. *Magnets annealed 20 minutes in aniline vapor.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | 1 | 24 | *0.566 | *20.1 | *29.5 | 1.28 | 2.76 | 32.2 |
| | 2 | 48 | 0.572 | 20.1 | 29.7 | 3.45 | 7.38 | 42.8 |
| | 3 | 70 | 0.568 | 20.1 | 29.6 | 5.38 | 11.41 | 45.9 |
| | 4 | 94 | 0.559 | 20.1 | 29.2 | 7.85 | 16.41 | 48.9 |
| II. | 5 | 20 | *0.536 | *20.0 | *27.4 | 0.92 | 1.98 | 29.1 |
| | 6 | 36 | *0.536 | *20.0 | *27.4 | 2.56 | 5.51 | 43.6 |
| | 7 | 57 | 0.534 | 20.0 | 27.3 | 4.51 | 9.62 | 48.9 |
| | 8 | 68 | 0.536 | 20.0 | 27.4 | 5.69 | 12.12 | 51.3 |
| | 9 | 120 | 0.539 | 20.0 | 27.5 | 11.05 | 22.69 | 55.0 |

7. *Magnets annealed 1 hour in aniline vapor.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | 1 | 24 | *0.545 | *18.9 | *28.4 | 1.36 | 2.93 | 34.1 |
| | 2 | 48 | 0.550 | 19.0 | 28.7 | 3.63 | 7.77 | 45.1 |
| | 3 | 70 | 0.546 | 19.0 | 28.5 | 5.64 | 11.96 | 48.1 |
| | 4 | 94 | 0.538 | 18.8 | 28.1 | 8.27 | 17.29 | 51.5 |
| II. | 5 | 20 | *0.514 | *18.8 | *26.3 | 0.94 | 2.04 | 30.0 |
| | 6 | 36 | *0.514 | *18.8 | *26.3 | 2.68 | 5.75 | 45.6 |
| | 7 | 57 | 0.515 | 19.0 | 26.4 | 4.75 | 10.14 | 51.5 |
| | 8 | 68 | 0.512 | 19.0 | 26.2 | 5.96 | 12.69 | 53.7 |
| | 9 | 120 | 0.514 | 18.5 | 26.3 | 11.66 | 23.94 | 58.0 |

8. *Magnets annealed 3 hours in aniline vapor.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | 1 | 24 | *0.520 | *18.9 | *27.1 | 1.44 | 3.09 | 36.1 |
| | 2 | 48 | 0.523 | 18.8 | 27.2 | 3.93 | 8.41 | 48.8 |
| | 3 | 70 | 0.523 | 18.9 | 27.3 | 6.17 | 13.08 | 52.6 |
| | 4 | 94 | 0.514 | 19.0 | 26.8 | 8.99 | 18.80 | 53.0 |
| II. | 5 | 20 | *0.488 | *18.8 | *24.9 | 1.00 | 2.16 | 31.8 |
| | 6 | 36 | *0.488 | *18.8 | *24.9 | 2.90 | 6.23 | 49.3 |
| | 7 | 57 | 0.487 | 18.7 | 24.9 | 5.16 | 11.01 | 55.9 |
| | 8 | 68 | 0.486 | 18.8 | 24.8 | 6.46 | 13.76 | 58.2 |
| | 9 | 120 | 0.490 | 19.0 | 24.9 | 12.68 | 26.03 | 63.1 |

9. *Magnets annealed 7 hours in aniline vapor.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | 1 | 24 | *0.500 | *20.0 | *25.9 | 1.51 | 3.25 | 37.9 |
| | 2 | 48 | 0.503 | 20.0 | 26.1 | 4.29 | 9.19 | 53.3 |
| | 3 | 70 | 0.502 | 20.0 | 26.0 | 6.72 | 14.26 | 57.3 |
| | 4 | 94 | 0.495 | 20.0 | 25.7 | 9.89 | 20.67 | 61.6 |
| II. | 5 | 20 | *0.466 | *20.0 | *23.7 | 1.09 | 2.36 | 34.7 |
| | 6 | 36 | *0.466 | *20.0 | *23.7 | 3.11 | 6.69 | 53.0 |
| | 7 | 57 | 0.465 | 20.0 | 23.6 | 5.63 | 12.02 | 61.0 |
| | 8 | 68 | 0.467 | 20.0 | 23.7 | 7.11 | 15.14 | 64.0 |
| | 9 | 120 | 0.467 | 20.0 | 23.7 | 13.88 | 28.50 | 69.0 |

TABLE 50.—*Relations between the magnetic constants of steel and hardness*—Continued.

10. *Magnets annealed 13 hours in aniline vapor.*

| Rod. | Magnet No. | a | W 1 m | t | $\frac{cm}{cm^2}$ 0° | n | M | m |
|---|---|---|---|---|---|---|---|---|
| | | | *ohm.* | °C. | *microhm.* | *cm.* | *abs. E.* | *abs. E.* |
| I.... | 1 | 24 | *0.483 | *19.9 | *25.0 | 1.50 | 3.42 | 29.9 |
| | 2 | 48 | 0.483 | 19.9 | 24.9 | 4.60 | 9.85 | 57.1 |
| | 3 | 70 | 0.485 | 19.9 | 25.1 | 7.19 | 15.25 | 61.3 |
| | 4 | 94 | 0.480 | 19.9 | 24.9 | 10.50 | 21.95 | 65.4 |
| II.... | 5 | 20 | *0.449 | *19.9 | *22.8 | 1.11 | 2.39 | 35.2 |
| | 6 | 36 | *0.449 | *19.9 | *22.8 | 3.30 | 7.09 | 56.2 |
| | 7 | 57 | 0.445 | 19.8 | 22.6 | 6.01 | 12.83 | 65.1 |
| | 8 | 68 | 0.449 | 19.0 | 22.7 | 7.66 | 16.31 | 69.1 |
| | 9 | 120 | 0.454 | 20.0 | 23.0 | 14.69 | 30.16 | 73.1 |

11. *Magnets annealed 1 minute in melting lead.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I.... | 1 | 24 | *0.397 | *18.6 | *20.4 | 1.57 | 3.38 | 38.4 |
| | 2 | 48 | 0.399 | 18.4 | 20.5 | 5.68 | 12.16 | 70.5 |
| | 3 | 70 | 0.397 | 18.7 | 20.4 | 9.44 | 20.02 | 80.5 |
| | 4 | 94 | 0.394 | 18.7 | 20.3 | 14.06 | 29.40 | 87.6 |
| II.... | 5 | 20 | *0.374 | *18.5 | *18.9 | 0.99 | 2.15 | 31.5 |
| | 6 | 36 | *0.374 | *18.5 | *18.9 | 3.58 | 7.68 | 69.9 |
| | 7 | 57 | 0.374 | 18.5 | 18.9 | 7.25 | 15.47 | 78.5 |
| | 8 | 68 | 0.373 | 18.7 | 18.8 | 9.32 | 19.85 | 84.0 |
| | 9 | 120 | 0.375 | 18.4 | 18.9 | 18.91 | 38.82 | 94.0 |

12. *Magnets annealed 1 hour in melting lead.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I.... | 1 | 24 | *0.367 | *18.8 | *18.8 | 1.45 | 3.11 | 36.3 |
| | 2 | 48 | 0.370 | 18.8 | 18.9 | 5.96 | 12.76 | 74.0 |
| | 3 | 70 | 0.367 | 18.8 | 18.8 | 10.13 | 21.48 | 86.4 |
| | 4 | 94 | 0.365 | 18.7 | 18.7 | 15.27 | 31.92 | 95.2 |
| II.... | 5 | 20 | *0.346 | *18.8 | *17.4 | 0.94 | 2.03 | 29.8 |
| | 6 | 36 | *0.346 | *18.8 | *17.4 | 3.59 | 7.71 | 61.1 |
| | 7 | 57 | 0.345 | 18.8 | 17.4 | 7.62 | 16.25 | 82.5 |
| | 8 | 68 | 0.345 | 18.8 | 17.3 | 9.96 | 21.22 | 89.8 |
| | 9 | 120 | 0.348 | 18.7 | 17.5 | 20.62 | 42.34 | 102.6 |

13. *Magnets annealed at red heat (soft).*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I.... | 1 | 24 | *0.302 | *15.1 | *15.7 | 0.32 | 0.69 | 8.0 |
| | 2 | 48 | 0.310 | 18.2 | 15.7 | 2.57 | 5.70 | 31.9 |
| | 3 | 70 | 0.308 | 18.2 | 15.7 | 6.21 | 13.18 | 53.0 |
| | 4 | 94 | 0.299 | 9.0 | 15.6 | 10.85 | 22.68 | 67.4 |
| II.... | 5 | 20 | *0.288 | *15.4 | *14.6 | 0.31 | 0.25 | 3.7 |
| | 6 | 36 | *0.288 | *15.4 | *14.6 | 1.39 | 2.90 | 23.7 |
| | 7 | 57 | 0.292 | 18.3 | 14.6 | 4.22 | 9.00 | 45.7 |
| | 8 | 68 | 0.292 | 18.3 | 14.6 | 6.07 | 12.93 | 54.7 |
| | 9 | 120 | 0.279 | 9.6 | 14.5 | 16.23 | 33.55 | 80.7 |

## RESULTS WITH RODS OF SMALLER DIMENSIONAL RATIO.

*Description of magnets.*—The rods used in the present experiments differ from the others principally in two respects: in the first place, the maximum of attainable hardness is here of much larger value than in

the earlier work; in the second, the degree of longitudinal homogeneity in the glass-hard state (and we may accept this as a fair evidence of structural uniformity throughout the chosen lengths) far surpasses that hitherto obtained. Hardness was carried even as far as $s = 47.5 \left(\frac{\text{cm}}{\text{cm}^2}\, 0^\circ \text{ microhm}\right)$.[129] In consequence of the exceptional homogeneity mentioned, we find that the magnetic data are in excellent accordance.

With the object of arriving at corroborative results, two pairs of wires of approximately identical degrees of galvanic hardness were selected. These are numbered IX, X, and XI, XII.[130] Each of these was broken into magnets such that the dimension-ratios $\alpha = 10, 20, 30, 40, 50$, obtained.[131] Certain important physical constants of these 20 magnets, Nos. 21 to 40, have for convenience of reference here been tabulated. The remarks which precede Table 49 apply to Table 51.

TABLE 51.—*Constants of magnets.*

| Rod $2\rho$ cm, $\Delta$ | Magnet No. | Mass $\mu$ | Length $L$. | Dim. ratio $\alpha$ |
|---|---|---|---|---|
| | | g | cm. | |
| IX $2\rho=0.147$, $\Delta=7.46$ | 21 | 0.184 | 1.45 | 9.9 |
| | 22 | 0.372 | 2.94 | 20.0 |
| | 23 | 0.570 | 4.50 | 30.6 |
| | 24 | 0.764 | 6.04 | 41.1 |
| | 25 | 0.953 | 7.52 | 51.2 |
| X $2\rho=0.149$, $\Delta=7.58$ | 26 | 0.194 | 1.46 | 9.8 |
| | 27 | 0.386 | 2.92 | 19.6 |
| | 28 | 0.593 | 4.49 | 30.1 |
| | 29 | 0.789 | 5.99 | 40.2 |
| | 30 | 0.998 | 7.56 | 50.7 |
| XI $2\rho=0.148$, $\Delta=7.70$ | 31 | 0.194 | 1.47 | 9.9 |
| | 32 | 0.401 | 3.01 | 20.2 |
| | 33 | 0.578 | 4.33 | 29.2 |
| | 34 | 0.799 | 6.00 | 40.5 |
| | 35 | 0.979 | 7.38 | 49.8 |
| XII $2\rho=0.151$, $\Delta=7.65$ | 36 | 0.208 | 1.51 | 10.0 |
| | 37 | 0.413 | 3.02 | 20.1 |
| | 38 | 0.634 | 4.62 | 30.6 |
| | 39 | 0.827 | 6.04 | 40.0 |
| | 40 | 1.040 | 7.58 | 50.2 |

*Homogeneity.*—The criterion for homogeneity was applied in the manner described in p. 121 by carefully examining the rod under experiment with reference to the electrical resistance of the parts between six equidistant points, about 5 centimeters apart. We believe it expedient to

[129] The maximum hardness observed with the older material was $s = 0.48$ Siemens units at 18°, therefore about $s = 44.5 \left(\frac{\text{cm}}{\text{cm}^2}\, 0^\circ \text{ microhm}\right)$. Cf. Wied. Ann., xi, p. 945, 1880.

[130] The rods III to IX and the magnets Nos. 11 to 20 are discussed in the following chapter.

[131] Of course this can only be done approximately. It is not easy to break a glass-hard rod accurately at a given point.

take the present opportunity of communicating some of these results by way of example. Table 52 contains (columns 2 to 5) the readings immediately taken from a Kohlrausch bridge. The measuring wire of this had been previously calibrated, with due allowance for the small corrections thus resulting. Column 1 shows which of the consecutive lengths (5.07 centimeters) of the steel rod corresponds to the given bridge reading, and the portion of the bridge-wire equivalent to 0.1 Siemens unit. Herefrom the absolute resistances (ohms) of the steel rods per 5.07 centimeters at $t°$ are calculated, and the values given in columns 6 to 9. In view of these very satisfactory results, we were justified in simplifying the subsequent work by testing the homogeneity of the four longest magnets only.

TABLE 52.—*Results for homogeneity.*

| | Bridge reading; scale parts. | | | | Resistance per length 5.07 cm. (ohm). | | | |
|---|---|---|---|---|---|---|---|---|
| | IX. | X. | XI. | XII. | IX. | X. | XI. | XII. |
| ..... | ..... | ..... | ..... | ..... | 0.017 | 0.013 | 0.013 | 0.012 |
| 1 | 70.1 | 69.0 | 67.2 | 66.1 | 0.026 | 0.085 | 0.011 | 0.054 |
| 2 | 70.4 | 68.9 | 67.1 | 66.1 | 0.033 | 0.083 | 0.009 | 0.054 |
| 3 | 70.6 | 69.0 | 67.2 | 66.2 | 0.037 | 0.085 | 0.011 | 0.056 |
| 4 | 70.8 | 68.9 | 67.5 | 66.3 | 0.040 | 0.083 | 0.016 | 0.058 |
| 5 | 70.7 | 69.0 | 67.5 | 66.3 | 0.039 | 0.085 | 0.016 | 0.058 |
| 0.1 S. U. | 468.1 | 474.3 | 488.3 | 502.0 | ..... | ..... | ..... | ..... |
| $t=$ | 10.8 | 10.8 | 11.0 | 11.0 | 10.8 | 10.8 | 11.0 | 11.0 |

*Magnetic data.*—In making the magnetic measurements we used the first position of Gauss. The numerical values of the constants occurring in the formulæ

$$m=\frac{M}{\mu} \qquad M=\frac{\frac{1}{2}\frac{r^3\,T\,\mathrm{tg}\,\varphi}{l^2}}{1+\frac{1}{2}\frac{r^3}{l^3}} \qquad 2\,\mathrm{tg}\,2\,\varphi=\frac{n}{R}$$

are as follows:

$$T=0.194\,\frac{g^{\frac{1}{2}}}{\mathrm{cm}^{\frac{1}{2}}\,\mathrm{sec.}} \qquad r=24.90\ \mathrm{cm.} \qquad R=232.8\ \mathrm{cm.}$$

The magnetic results of our experiments, finally, are given in the series forming table (53):

TABLE 53.—*Relation between the magnetic constants of steel and hardness.*

1. *Magnets in the glass-hard state.*

| Rod. | Magnet No. | a | $W$ 1 m | $t$ | $s\frac{\mathrm{cm}}{\mathrm{cm}^3}\varrho°$ | $n$ | $M$ | $m$ |
|---|---|---|---|---|---|---|---|---|
| | | | ohm. | °C. | microhm. | cm. | abs. E. | abs. E. |
| IX.. | 21 | 9.9 | 0.283 | 10.8 | 47.2 | 2.60 | 4.17 | 8.7 |
| | 22 | 20.0 | 0.283 | 10.8 | 47.2 | 8.32 | 13.31 | 15.8 |
| | 23 | 30.6 | 0.283 | 10.8 | 47.2 | 14.86 | 23.62 | 41.4 |
| | 24 | 41.1 | 0.283 | 10.8 | 47.2 | 21.37 | 33.64 | 44.0 |
| | 25 | 51.2 | 0.283 | 10.8 | 47.2 | 28.18 | 43.86 | 46.0 |

TABLE 53.—*Relation between the magnetic constants of steel and hardness*—Continued.

1. *Magnets in the glass-hard state*—Continued.

| Rod. | Magnet No. | a | W l m | t | $s\frac{cm}{cm^3}0^\circ$ | n | M | m |
|---|---|---|---|---|---|---|---|---|
| | | | ohm. | °C. | *microhm.* | *cm.* | *abs. E.* | *abs. E.* |
| X.. | 26 | 9.8 | 0.273 | 11.2 | 46.8 | 2.82 | 4.53 | 23.3 |
| | 27 | 19.6 | 0.273 | 11.2 | 46.8 | 8.88 | 14.21 | 36.8 |
| | 28 | 30.1 | 0.273 | 11.2 | 46.8 | 15.82 | 25.14 | 42.4 |
| | 29 | 40.2 | 0.273 | 11.2 | 46.8 | 22.45 | 35.36 | 44.8 |
| | 30 | 50.7 | 0.273 | 11.2 | 46.8 | 29.75 | 46.30 | 46.4 |
| XI.. | 31 | 9.9 | 0.259 | 11.0 | 43.8 | 2.99 | 4.80 | 24.8 |
| | 32 | 20.3 | 0.259 | 11.0 | 43.8 | 10.27 | 16.43 | 41.0 |
| | 33 | 29.2 | 0.259 | 11.0 | 43.8 | 17.16 | 27.30 | 47.2 |
| | 34 | 40.5 | 0.259 | 11.0 | 43.8 | 25.77 | 40.59 | 50.8 |
| | 35 | 49.8 | 0.259 | 11.0 | 43.8 | 32.98 | 51.40 | 52.5 |
| XII.. | 36 | 10.0 | 0.248 | 11.0 | 43.5 | 2.96 | 4.79 | 23.0 |
| | 37 | 20.1 | 0.248 | 11.0 | 43.5 | 9.53 | 15.24 | 36.9 |
| | 38 | 30.6 | 0.248 | 11.0 | 43.5 | 17.32 | 27.50 | 43.4 |
| | 39 | 40.0 | 0.248 | 11.0 | 43.5 | 24.33 | 38.30 | 46.3 |
| | 40 | 50.2 | 0.248 | 11.0 | 43.5 | 32.28 | 50.22 | 48.3 |

2. *Magnets annealed 1 hour in steam.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IX.. | 21 | 9.9 | 0.252 | 11.8 | 42.0 | 2.43 | 3.90 | 21.2 |
| | 22 | 20.0 | 0.252 | 11.8 | 42.0 | 7.80 | 12.48 | 33.6 |
| | 23 | 30.6 | 0.252 | 11.8 | 42.0 | 13.92 | 22.12 | 38.8 |
| | 24 | 41.1 | 0.252 | 11.8 | 42.0 | 20.05 | 31.56 | 41.3 |
| | 25 | 51.2 | 0.252 | 11.8 | 42.0 | 26.47 | 41.21 | 43.2 |
| X.. | 26 | 9.8 | 0.244 | 12.0 | 41.7 | 2.66 | 4.27 | 22.0 |
| | 27 | 19.6 | 0.244 | 12.0 | 41.7 | 8.30 | 13.28 | 34.4 |
| | 28 | 30.1 | 0.244 | 12.0 | 41.7 | 14.88 | 23.65 | 39.9 |
| | 29 | 40.2 | 0.244 | 12.0 | 41.7 | 21.08 | 33.20 | 42.1 |
| | 30 | 50.7 | 0.244 | 12.0 | 41.7 | 27.95 | 43.50 | 43.6 |
| XI.. | 31 | 9.9 | 0.229 | 12.0 | 38.6 | 2.82 | 4.53 | 23.3 |
| | 32 | 20.3 | 0.229 | 12.0 | 38.6 | 9.83 | 15.78 | 39.2 |
| | 33 | 29.2 | 0.229 | 12.0 | 38.6 | 16.42 | 26.12 | 45.2 |
| | 34 | 40.5 | 0.229 | 12.0 | 38.6 | 24.59 | 38.89 | 48.7 |
| | 35 | 49.8 | 0.229 | 12.0 | 38.6 | 31.63 | 49.29 | 50.4 |
| XII.. | 36 | 10.0 | 0.219 | 12.0 | 38.4 | 2.86 | 4.59 | 22.1 |
| | 37 | 20.1 | 0.219 | 12.0 | 38.4 | 9.20 | 14.72 | 35.6 |
| | 38 | 30.6 | 0.219 | 12.0 | 38.4 | 16.70 | 26.52 | 41.8 |
| | 39 | 40.0 | 0.219 | 12.0 | 38.4 | 23.43 | 36.89 | 44.6 |
| | 40 | 50.2 | 0.219 | 12.0 | 38.4 | 31.15 | 48.47 | 46.6 |

3. *Magnets annealed 3 hours in steam.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IX.. | 21 | 9.9 | 0.238 | 11.9 | 39.5 | 2.46 | 3.94 | 21.4 |
| | 22 | 20.0 | 0.238 | 11.9 | 39.5 | 7.72 | 12.34 | 33.2 |
| | 23 | 30.6 | 0.238 | 11.9 | 39.5 | 13.69 | 21.76 | 38.2 |
| | 24 | 41.1 | 0.238 | 11.9 | 39.5 | 19.72 | 31.05 | 40.6 |
| | 25 | 51.2 | 0.238 | 11.9 | 39.5 | 25.89 | 40.30 | 42.3 |
| X.. | 26 | 9.8 | 0.230 | 11.8 | 39.3 | 2.70 | 4.34 | 22.4 |
| | 27 | 19.6 | 0.230 | 11.8 | 39.3 | 8.21 | 13.13 | 34.0 |
| | 28 | 30.1 | 0.230 | 11.8 | 39.3 | 14.62 | 23.23 | 39.2 |
| | 29 | 40.2 | 0.230 | 11.8 | 39.3 | 20.65 | 32.52 | 41.2 |
| | 30 | 50.7 | 0.230 | 11.8 | 39.3 | 27.34 | 42.55 | 42.6 |
| XI.. | 31 | 9.9 | 0.216 | 12.0 | 36.5 | 2.83 | 4.54 | 23.4 |
| | 32 | 20.3 | 0.216 | 12.0 | 36.5 | 9.68 | 15.49 | 38.6 |
| | 33 | 29.2 | 0.216 | 12.0 | 36.5 | 16.16 | 25.70 | 44.5 |
| | 34 | 40.5 | 0.216 | 12.0 | 36.5 | 24.21 | 38.13 | 47.7 |
| | 35 | 49.8 | 0.216 | 12.0 | 36.5 | 30.94 | 48.22 | 49.3 |
| XII.. | 36 | 10.0 | 0.207 | 12.0 | 36.2 | 2.88 | 4.63 | 22.2 |
| | 37 | 20.1 | 0.207 | 12.0 | 36.2 | 9.13 | 14.59 | 35.3 |
| | 38 | 30.6 | 0.207 | 12.0 | 36.2 | 16.50 | 26.21 | 41.3 |
| | 39 | 40.0 | 0.207 | 12.0 | 36.2 | 23.09 | 36.35 | 43.9 |
| | 40 | 50.2 | 0.207 | 12.0 | 36.2 | 30.57 | 47.57 | 45.7 |

TABLE 53.—*Relation between the magnetic constants of steel and hardness*—Continued.

4. *Magnets annealed 6 hours in steam.*

| Rod. | Magnet No. | $\sigma$ | $W1m$ | $t$ | $s\frac{cm}{cm^2}o$ | $n$ | $M$ | $m$ |
|---|---|---|---|---|---|---|---|---|
| | | | *ohm.* | °C | *mic rohm.* | *cm.* | *abs. E.* | *abs. E.* |
| IX.. | 21 | 9.9 | 0.230 | 11.9 | 38.2 | 2.48 | 3.98 | 21.6 |
| | 22 | 20.0 | 0.230 | 11.9 | 38.2 | 7.72 | 12.35 | 32.2 |
| | 23 | 30.6 | 0.230 | 11.9 | 38.2 | 13.70 | 21.77 | 38.2 |
| | 24 | 41.1 | 0.230 | 11.9 | 38.2 | 19.63 | 30.90 | 40.4 |
| | 25 | 51.2 | 0.230 | 11.9 | 38.2 | 25.80 | 40.16 | 42.1 |
| X.. | 26 | 9.8 | 0.223 | 11.9 | 38.0 | 2.70 | 4.34 | 22.4 |
| | 27 | 19.6 | 0.223 | 11.9 | 38.0 | 8.21 | 13.13 | 34.0 |
| | 28 | 30.1 | 0.223 | 11.9 | 38.0 | 14.53 | 23.09 | 38.9 |
| | 29 | 40.2 | 0.223 | 11.9 | 38.0 | 20.55 | 32.37 | 41.9 |
| | 30 | 50.7 | 0.223 | 11.9 | 38.0 | 27.24 | 42.39 | 42.5 |
| XI.. | 31 | 9.9 | 0.209 | 11.8 | 35.1 | 2.82 | 4.53 | 23.3 |
| | 32 | 20.3 | 0.209 | 11.8 | 35.1 | 9.68 | 15.49 | 36.6 |
| | 33 | 29.2 | 0.209 | 11.8 | 35.1 | 16.09 | 25.60 | 44.3 |
| | 34 | 40.5 | 0.209 | 11.8 | 35.1 | 24.05 | 37.88 | 47.6 |
| | 35 | 49.8 | 0.209 | 11.8 | 35.1 | 30.82 | 48.03 | 48.1 |
| XII.. | 36 | 10.0 | 0.199 | 11.8 | 34.9 | 2.84 | 4.56 | 21.9 |
| | 37 | 20.1 | 0.199 | 11.8 | 34.9 | 9.12 | 14.59 | 35.1 |
| | 38 | 30.6 | 0.199 | 11.8 | 34.9 | 16.39 | 26.03 | 41.1 |
| | 39 | 40.0 | 0.199 | 11.8 | 34.9 | 22.92 | 36.08 | 43.6 |
| | 40 | 50.2 | 0.199 | 11.8 | 34.9 | 30.41 | 47.32 | 45.5 |

5. *Magnets annealed 10 hours in steam.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IX.. | 21 | 9.9 | 0.226 | 11.8 | 37.4 | 2.46 | 3.95 | 21.5 |
| | 22 | 20.0 | 0.226 | 11.8 | 37.4 | 7.73 | 12.37 | 33.1 |
| | 23 | 30.6 | 0.226 | 11.8 | 37.4 | 13.69 | 21.76 | 38.2 |
| | 24 | 41.1 | 0.226 | 11.8 | 37.4 | 19.66 | 30.95 | 40.5 |
| | 25 | 51.2 | 0.226 | 11.8 | 37.4 | 25.83 | 40.21 | 42.2 |
| X.. | 26 | 9.8 | 0.218 | 11.9 | 37.1 | 2.70 | 4.34 | 22.4 |
| | 27 | 19.6 | 0.218 | 11.9 | 37.1 | 8.19 | 13.10 | 33.9 |
| | 28 | 30.1 | 0.218 | 11.9 | 37.1 | 14.57 | 23.16 | 38.8 |
| | 29 | 40.2 | 0.218 | 11.9 | 37.1 | 20.60 | 32.45 | 41.1 |
| | 30 | 50.7 | 0.218 | 11.9 | 37.1 | 27.25 | 42.41 | 42.5 |
| XI.. | 31 | 9.9 | 0.204 | 11.9 | 34.3 | 2.81 | 4.51 | 23.3 |
| | 32 | 20.3 | 0.204 | 11.9 | 34.3 | 9.61 | 15.37 | 36.1 |
| | 33 | 29.2 | 0.204 | 11.9 | 34.3 | 16.06 | 25.54 | 44.2 |
| | 34 | 40.5 | 0.204 | 11.9 | 34.3 | 24.03 | 37.85 | 47.4 |
| | 35 | 49.8 | 0.204 | 11.9 | 34.3 | 30.74 | 47.91 | 48.9 |
| XII.. | 36 | 10.0 | 0.195 | 11.9 | 34.0 | 2.87 | 4.61 | 22.2 |
| | 37 | 20.1 | 0.195 | 11.9 | 34.0 | 9.09 | 14.54 | 35.2 |
| | 38 | 30.6 | 0.195 | 11.9 | 34.0 | 16.34 | 25.95 | 44.9 |
| | 39 | 40.0 | 0.195 | 11.9 | 34.0 | 22.87 | 36.01 | 43.5 |
| | 40 | 50.2 | 0.195 | 11.9 | 34.0 | 30.37 | 47.25 | 45.4 |

6. *Magnets annealed 20 minutes in aniline vapor.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IX.. | 21 | 9.9 | 0.191 | 12.0 | 31.5 | 2.31 | 3.71 | 20.2 |
| | 22 | 20.0 | 0.191 | 12.0 | 31.5 | 7.97 | 12.75 | 34.3 |
| | 23 | 30.6 | 0.191 | 12.0 | 31.5 | 14.60 | 23.21 | 40.7 |
| | 24 | 41.1 | 0.191 | 12.0 | 31.5 | 21.15 | 33.30 | 43.6 |
| | 25 | 51.2 | 0.191 | 12.0 | 31.5 | 28.02 | 43.62 | 45.8 |
| X.. | 26 | 9.8 | 0.185 | 12.0 | 31.4 | 2.60 | 4.18 | 21.5 |
| | 27 | 19.6 | 0.185 | 12.0 | 31.4 | 8.45 | 13.52 | 35.0 |
| | 28 | 30.1 | 0.185 | 12.0 | 31.4 | 15.48 | 24.60 | 41.3 |
| | 29 | 40.2 | 0.185 | 12.0 | 31.4 | 22.22 | 34.99 | 44.4 |
| | 30 | 50.7 | 0.185 | 12.0 | 31.4 | 29.58* | 46.04 | 46.1 |
| XI.. | 31 | 9.9 | 0.173 | 12.0 | 29.0 | 2.54 | 4.08 | 21.0 |
| | 32 | 20.3 | 0.173 | 12.0 | 29.0 | 9.75 | 15.60 | 36.9 |
| | 33 | 29.2 | 0.173 | 12.0 | 29.0 | 16.70 | 26.56 | 45.0 |
| | 34 | 40.5 | 0.173 | 12.0 | 29.0 | 25.52 | 40.20 | 50.1 |
| | 35 | 49.8 | 0.173 | 12.0 | 29.0 | 32.87 | 51.23 | 52.3 |
| XII.. | 36 | 10.0 | 0.165 | 12.0 | 28.7 | 2.67 | 4.29 | 20.6 |
| | 37 | 20.1 | 0.165 | 12.0 | 28.7 | 9.28 | 14.84 | 35.9 |
| | 38 | 30.6 | 0.165 | 12.0 | 28.7 | 17.31 | 27.49 | 43.7 |
| | 39 | 40.0 | 0.165 | 12.0 | 28.7 | 24.52 | 38.60 | 46.9 |
| | 40 | 50.2 | 0.165 | 12.0 | 28.7 | 32.75 | 50.96 | 49.4 |

TABLE 53.—*Relation between the magnetic constants of steel and hardness*—Continued.

7. *Magnets annealed 1 hour in aniline vapor.*

| Rod. | Magnet No. | a | $W1m$ | t | $s\frac{cm_0}{cm^2}$ | n | M | m |
|---|---|---|---|---|---|---|---|---|
| | | | *ohm.* | °C. | *microhm.* | *cm.* | *abs. E.* | *abs. E.* |
| IX.. | 21 | 9.9 | 0.179 | 12.0 | 29.7 | 2.33 | 3.75 | 20.4 |
| | 22 | 20.0 | 0.179 | 12.0 | 29.7 | 8.80 | 13.28 | 35.7 |
| | 23 | 30.6 | 0.179 | 12.0 | 29.7 | 15.38 | 24.45 | 42.9 |
| | 24 | 41.1 | 0.179 | 12.0 | 29.7 | 22.37 | 35.22 | 46.1 |
| | 25 | 51.2 | 0.179 | 12.0 | 29.7 | 29.75 | 46.31 | 48.6 |
| X.. | 26 | 9.8 | 0.175 | 12.0 | 29.6 | 2.52 | 4.05 | 20.9 |
| | 27 | 19.6 | 0.175 | 12.0 | 29.6 | 8.79 | 14.06 | 36.4 |
| | 28 | 30.1 | 0.175 | 12.0 | 29.6 | 16.31 | 25.92 | 43.7 |
| | 29 | 40.2 | 0.175 | 12.0 | 29.6 | 23.60 | 37.17 | 47.1 |
| | 30 | 50.7 | 0.175 | 12.0 | 29.6 | 31.46 | 48.97 | 49.1 |
| XI.. | 31 | 9.9 | 0.164 | 12.0 | 27.5 | 2.57 | 4.13 | 21.3 |
| | 32 | 20.3 | 0.164 | 12.0 | 27.5 | 10.08 | 16.13 | 40.2 |
| | 33 | 29.2 | 0.164 | 12.0 | 27.5 | 17.49 | 27.82 | 48.1 |
| | 34 | 40.5 | 0.164 | 12.0 | 27.5 | 26.53 | 42.26 | 52.9 |
| | 35 | 49.8 | 0.164 | 12.0 | 27.5 | 34.64 | 53.99 | 55.1 |
| XII.. | 36 | 10.0 | 0.157 | 12.0 | 27.3 | 2.66 | 4.27 | 20.5 |
| | 37 | 20.1 | 0.157 | 12.0 | 27.3 | 9.60 | 15.36 | 37.2 |
| | 38 | 30.6 | 0.157 | 12.0 | 27.3 | 18.19 | 28.89 | 45.6 |
| | 39 | 40.0 | 0.157 | 12.0 | 27.3 | 25.88 | 40.75 | 49.3 |
| | 40 | 50.2 | 0.157 | 12.0 | 27.3 | 34.63 | 53.89 | 51.8 |

8. *Magnets annealed 3 hours in aniline vapor.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IX.. | 21 | 9.9 | 0.169 | 11.7 | 27.9 | 2.41 | 3.87 | 21.0 |
| | 22 | 20.0 | 0.169 | 11.7 | 27.9 | 8.99 | 14.38 | 38.7 |
| | 23 | 30.6 | 0.169 | 11.7 | 27.9 | 16.93 | 26.91 | 47.2 |
| | 24 | 41.1 | 0.169 | 11.7 | 27.9 | 24.75 | 38.97 | 51.0 |
| | 25 | 51.2 | 0.169 | 11.7 | 27.9 | 32.94 | 51.27 | 53.8 |
| X.. | 26 | 9.8 | 0.164 | 11.8 | 27.7 | 2.62 | 4.21 | 21.7 |
| | 27 | 19.6 | 0.164 | 11.8 | 27.7 | 9.56 | 15.30 | 39.6 |
| | 28 | 30.1 | 0.164 | 11.8 | 27.7 | 18.06 | 28.73 | 48.5 |
| | 29 | 40.2 | 0.164 | 11.8 | 27.7 | 26.23 | 41.31 | 52.4 |
| | 30 | 50.7 | 0.164 | 11.8 | 27.7 | 35.06 | 54.56 | 54.7 |
| XI.. | 31 | 9.9 | 0.153 | 11.8 | 25.6 | 2.61 | 4.19 | 21.6 |
| | 32 | 20.3 | 0.153 | 11.8 | 25.6 | 10.71 | 17.13 | 42.7 |
| | 33 | 29.2 | 0.153 | 11.8 | 25.6 | 18.96 | 30.19 | 52.2 |
| | 34 | 40.5 | 0.153 | 11.8 | 25.6 | 29.25 | 46.07 | 57.7 |
| | 35 | 49.8 | 0.153 | 11.8 | 25.6 | 37.83 | 58.95 | 60.2 |
| XII.. | 36 | 10.0 | 0.147 | 11.9 | 25.5 | 2.75 | 4.42 | 21.2 |
| | 37 | 20.1 | 0.147 | 11.9 | 25.5 | 10.29 | 16.46 | 39.8 |
| | 38 | 30.6 | 0.147 | 11.9 | 25.5 | 19.81 | 31.46 | 49.6 |
| | 39 | 40.0 | 0.147 | 11.9 | 25.5 | 28.37 | 44.67 | 54.0 |
| | 40 | 50.2 | 0.147 | 11.9 | 25.5 | 38.16 | 59.37 | 57.1 |

9. *Magnets annealed 7 hours in aniline vapor.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IX.. | 21 | 9.9 | 0.159 | 12.0 | 26.2 | 2.53 | 4.06 | 22.1 |
| | 22 | 20.0 | 0.159 | 12.0 | 26.2 | 9.80 | 15.68 | 42.2 |
| | 23 | 30.6 | 0.159 | 12.0 | 26.2 | 18.73 | 29.78 | 52.2 |
| | 24 | 41.1 | 0.159 | 12.0 | 26.2 | 27.65 | 43.53 | 57.0 |
| | 25 | 51.2 | 0.159 | 12.0 | 26.2 | 37.03 | 57.65 | 60.5 |
| X.. | 26 | 9.8 | 0.154 | 12.0 | 26.0 | 2.68 | 4.30 | 22.2 |
| | 27 | 19.6 | 0.154 | 12.0 | 26.0 | 10.36 | 16.58 | 42.9 |
| | 28 | 30.1 | 0.154 | 12.0 | 26.0 | 20.06 | 31.88 | 53.8 |
| | 29 | 40.2 | 0.154 | 12.0 | 26.0 | 29.31 | 46.16 | 58.5 |
| | 30 | 50.7 | 0.154 | 12.0 | 26.0 | 39.39 | 61.31 | 61.4 |
| XI.. | 31 | 9.9 | 0.145 | 12.0 | 24.2 | 2.63 | 4.22 | 21.8 |
| | 32 | 20.3 | 0.145 | 12.0 | 24.2 | 11.40 | 18.24 | 45.5 |
| | 33 | 29.2 | 0.145 | 12.0 | 24.2 | 20.69 | 33.92 | 56.9 |
| | 34 | 40.5 | 0.145 | 12.0 | 24.2 | 32.19 | 50.70 | 63.5 |
| | 35 | 49.8 | 0.145 | 12.0 | 24.2 | 41.96 | 65.39 | 66.8 |
| XII.. | 36 | 10.0 | 0.138 | 12.0 | 22.9 | 2.80 | 4.50 | 21.6 |
| | 37 | 20.1 | 0.138 | 12.0 | 22.9 | 11.01 | 17.61 | 42.6 |
| | 38 | 30.6 | 0.138 | 12.0 | 22.9 | 21.73 | 34.51 | 54.4 |
| | 39 | 40.0 | 0.138 | 12.0 | 22.9 | 31.32 | 49.31 | 59.6 |
| | 40 | 50.2 | 0.138 | 12.0 | 22.9 | 42.37 | 65.98 | 63.4 |

TABLE 53.—*Relation between the magnetic constants of steel and hardness*—Continued.

10. *Magnets annealed 13 hours in aniline vapor.*

| Rod. | Magnet No. | a | W 1 m | t | $s\frac{cm}{cm^3}0°$ | n | M | u |
|---|---|---|---|---|---|---|---|---|
| | | | ohm. | °C. | microhm. | cm. | abs. E. | abs. E. |
| IX.. | 21 | 9.9 | 0.151 | 12.0 | 24.8 | 2.50 | 4.02 | 21.8 |
| | 22 | 20.0 | 0.151 | 12.0 | 24.8 | 10.25 | 16.40 | 44.1 |
| | 23 | 30.6 | 0.151 | 12.0 | 24.8 | 20.09 | 31.93 | 58.1 |
| | 24 | 41.1 | 0.151 | 12.0 | 24.8 | 30.92 | 47.26 | 61.1 |
| | 25 | 51.2 | 0.151 | 12.0 | 24.8 | 40.25 | 62.66 | 65.8 |
| X.. | 26 | 9.8 | 0.146 | 12.0 | 24.6 | 2.64 | 4.24 | 21.9 |
| | 27 | 19.6 | 0.146 | 12.0 | 24.6 | 10.79 | 17.26 | 44.7 |
| | 28 | 30.1 | 0.146 | 12.0 | 24.6 | 21.59 | 34.32 | 57.9 |
| | 29 | 40.2 | 0.146 | 12.0 | 24.6 | 31.87 | 50.20 | 61.6 |
| | 30 | 50.7 | 0.146 | 12.0 | 24.6 | 42.96 | 66.87 | 62.0 |
| XI.. | 31 | 9.9 | 0.188 | 12.0 | 22.9 | 2.53 | 4.06 | 20.9 |
| | 32 | 20.3 | 0.188 | 12.0 | 22.9 | 11.59 | 18.54 | 46.2 |
| | 33 | 29.2 | 0.188 | 12.0 | 22.9 | 21.68 | 34.49 | 58.7 |
| | 34 | 40.5 | 0.188 | 12.0 | 22.9 | 34.53 | 54.39 | 68.1 |
| | 35 | 49.8 | 0.188 | 12.0 | 22.9 | 45.08 | 70.26 | 71.8 |
| XII.. | 36 | 10.0 | 0.132 | 12.0 | 22.7 | 2.73 | 4.38 | 21.1 |
| | 37 | 20.1 | 0.132 | 12.0 | 22.7 | 11.30 | 18.08 | 43.8 |
| | 38 | 30.6 | 0.132 | 12.0 | 22.7 | 22.90 | 36.37 | 57.4 |
| | 39 | 40.0 | 0.132 | 12.0 | 22.7 | 33.50 | 52.74 | 63.8 |
| | 40 | 50.2 | 0.132 | 12.0 | 22.7 | 45.60 | 70.96 | 68.2 |

11. *Magnets annealed 10 minutes in melting tin.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IX.. | 21 | 9.9 | 0.147 | 11.7 | 24.0 | 2.46 | 3.95 | 21.5 |
| | 22 | 20.0 | 0.147 | 11.7 | 24.0 | 10.37 | 16.59 | 44.6 |
| | 23 | 30.6 | 0.147 | 11.7 | 24.0 | 20.64 | 32.80 | 57.5 |
| | 24 | 41.1 | 0.147 | 11.7 | 24.0 | 30.97 | 48.75 | 63.2 |
| | 25 | 51.2 | 0.147 | 11.7 | 24.0 | 41.92 | 65.25 | 66.5 |
| X.. | 26 | 9.8 | 0.141 | 11.5 | 23.8 | 2.60 | 4.16 | 21.5 |
| | 27 | 19.6 | 0.141 | 11.5 | 23.8 | 10.98 | 17.57 | 45.5 |
| | 28 | 30.1 | 0.141 | 11.5 | 23.8 | 22.28 | 35.41 | 58.7 |
| | 29 | 40.2 | 0.141 | 11.5 | 23.8 | 33.11 | 52.16 | 66.1 |
| | 30 | 50.7 | 0.141 | 11.5 | 23.8 | 44.78 | 69.70 | 69.8 |
| XI.. | 31 | 9.9 | 0.134 | 11.6 | 22.2 | 2.46 | 3.95 | 20.4 |
| | 32 | 20.3 | 0.134 | 11.6 | 22.2 | 11.70 | 18.72 | 46.7 |
| | 33 | 29.2 | 0.134 | 11.6 | 22.2 | 22.17 | 35.27 | 61.0 |
| | 34 | 40.5 | 0.134 | 11.6 | 22.2 | 35.60 | 56.07 | 70.2 |
| | 35 | 49.8 | 0.134 | 11.6 | 22.2 | 46.70 | 72.78 | 74.3 |
| XII.. | 36 | 10.0 | 0.127 | 11.7 | 22.0 | 2.68 | 4.30 | 20.7 |
| | 37 | 20.1 | 0.127 | 11.7 | 22.0 | 11.37 | 18.19 | 44.6 |
| | 38 | 30.6 | 0.127 | 11.7 | 22.0 | 23.47 | 37.27 | 58.8 |
| | 39 | 40.0 | 0.127 | 11.7 | 22.0 | 34.58 | 54.44 | 65.8 |
| | 40 | 50.2 | 0.127 | 11.7 | 22.0 | 47.29 | 73.59 | 70.8 |

12. *Magnets annealed 1 minute in melting lead.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IX.. | 21 | 9.9 | 0.124 | 11.9 | 20.3 | 2.26 | 3.60 | 18.7 |
| | 22 | 20.0 | 0.124 | 11.9 | 20.3 | 10.88 | 17.40 | 45.8 |
| | 23 | 30.6 | 0.124 | 11.9 | 20.3 | 24.04 | 38.19 | 67.8 |
| | 24 | 41.1 | 0.124 | 11.9 | 20.3 | 38.43 | 60.51 | 79.2 |
| | 25 | 51.2 | 0.124 | 11.9 | 20.3 | 52.53 | 81.77 | 85.8 |
| X.. | 26 | 9.8 | 0.120 | 11.3 | 20.1 | 2.33 | 3.74 | 19.3 |
| | 27 | 19.6 | 0.120 | 11.3 | 20.1 | 11.14 | 17.83 | 46.2 |
| | 28 | 30.1 | 0.120 | 11.3 | 20.1 | 25.84 | 40.27 | 67.9 |
| | 29 | 40.2 | 0.120 | 11.3 | 20.1 | 40.08 | 62.12 | 80.0 |
| | 30 | 50.7 | 0.120 | 11.3 | 20.1 | 55.46 | 86.32 | 86.5 |
| XI.. | 31 | 9.9 | 0.115 | 11.9 | 19.0 | 2.30 | 3.69 | 19.0 |
| | 32 | 20.3 | 0.115 | 11.9 | 19.0 | 11.71 | 18.72 | 46.7 |
| | 33 | 29.2 | 0.115 | 11.9 | 19.0 | 24.71 | 39.30 | 68.0 |
| | 34 | 40.5 | 0.115 | 11.9 | 19.0 | 42.45 | 66.87 | 83.7 |
| | 35 | 49.8 | 0.115 | 11.9 | 19.0 | 56.53 | 88.10 | 90.0 |
| XII.. | 36 | 10.0 | 0.109 | 11.9 | 18.7 | 2.46 | 3.95 | 18.0 |
| | 37 | 20.1 | 0.109 | 11.9 | 18.7 | 11.18 | 17.89 | 43.3 |
| | 38 | 30.6 | 0.109 | 11.9 | 18.7 | 25.95 | 41.21 | 65.0 |
| | 39 | 40.0 | 0.109 | 11.9 | 18.7 | 41.39 | 65.16 | 78.8 |
| | 40 | 50.2 | 0.109 | 11.9 | 18.7 | 58.01 | 90.26 | 86.8 |

TABLE 53.—*Relation between the magnetic constants of steel and hardness*—Continued.

13. *Magnets annealed 1 hour in melting zinc.*

| Rod. | Magnet No. | $a$ | $W$ i m | $t$ | $s\frac{cm}{cm^2}0^o$ | $n$ | $M$ | $m$ |
|---|---|---|---|---|---|---|---|---|
| | | | *ohm.* | °C. | *microhm.* | *cm.* | *abs. E.* | *abs. E.* |
| IX.. | 21 | 9.9 | 0.107 | 10.3 | 17.5 | 1.85 | 2.98 | 16.2 |
| | 22 | 20.0 | 0.107 | 10.3 | 17.5 | 10.15 | 16.24 | 43.7 |
| | 23 | 30.6 | 0.107 | 10.3 | 17.5 | 26.02 | 41.35 | 72.5 |
| | 24 | 41.1 | 0.107 | 10.3 | 17.5 | 43.90 | 69.12 | 90.5 |
| | 25 | 51.2 | 0.107 | 10.3 | 17.5 | 61.65 | 95.96 | 100.7 |
| X.. | 26 | 9.8 | 0.102 | 10.3 | 17.2 | 1.83 | 2.94 | 15.2 |
| | 27 | 19.6 | 0.102 | 10.3 | 17.2 | 9.82 | 15.71 | 40.7 |
| | 28 | 30.1 | 0.102 | 10.3 | 17.2 | 26.89 | 42.64 | 72.1 |
| | 29 | 40.2 | 0.102 | 10.3 | 17.2 | 46.03 | 72.49 | 91.9 |
| | 30 | 50.7 | 0.102 | 10.3 | 17.2 | 65.10 | 101.32 | 101.5 |
| XI.. | 31 | 9.9 | 0.098 | 10.3 | 16.2 | 1.74 | 2.79 | 14.4 |
| | 32 | 20.3 | 0.098 | 10.3 | 16.2 | 10.06 | 16.09 | 40.1 |
| | 33 | 29.2 | 0.098 | 10.3 | 16.2 | 26.87 | 42.74 | 72.6 |
| | 34 | 40.5 | 0.098 | 10.3 | 16.2 | 47.63 | 75.03 | 93.9 |
| | 35 | 49.8 | 0.098 | 10.3 | 16.2 | 65.29 | 101.74 | 103.9 |
| XII.. | 36 | 10.0 | 0.093 | 10.3 | 16.0 | 1.93 | 3.10 | 14.9 |
| | 37 | 20.1 | 0.093 | 10.3 | 16.0 | 9.95 | 15.91 | 38.5 |
| | 38 | 30.6 | 0.093 | 10.3 | 16.0 | 27.14 | 43.10 | 68.0 |
| | 39 | 40.0 | 0.093 | 10.3 | 16.0 | 46.73 | 73.57 | 89.0 |
| | 40 | 50.2 | 0.093 | 10.3 | 16.0 | 67.60 | 105.17 | 101.1 |

14. *Magnets annealed at red heat (soft).*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IX.. | 21 | 9.9 | 0.096 | 10.0 | 15.7 | 0.52 | 0.83 | 4.5 |
| | 22 | 20.0 | 0.096 | 10.0 | 15.7 | 2.72 | 4.35 | 11.7 |
| | 23 | 30.6 | 0.096 | 10.0 | 15.7 | 7.94 | 12 62 | 22.1 |
| | 24 | 41.1 | 0.096 | 10.0 | 15.7 | 10.87 | 26.56 | 34.8 |
| | 25 | 51.2 | 0.096 | 10.0 | 15.7 | 28.49 | 44.35 | 46.5 |
| X.. | 26 | 9.8 | 0.093 | 10.1 | 15.6 | 0.46 | 0.74 | 3.8 |
| | 27 | 19.6 | 0.093 | 10.1 | 15.6 | 2.52 | 4.03 | 10.5 |
| | 28 | 30.1 | 0.093 | 10.1 | 15.6 | 7.59 | 12.06 | 20.3 |
| | 29 | 40.2 | 0.093 | 10.1 | 15.6 | 15.72 | 24.73 | 31.4 |
| | 30 | 50.7 | 0.093 | 10.1 | 15.6 | 29.15 | 45 >6 | 45.4 |
| XI.. | 31 | 9.9 | 0.096 | 10.2 | 14.9 | 0.32 | 0.84 | 4.3 |
| | 32 | 20.3 | 0.096 | 10.2 | 14.9 | 2.55 | 4.08 | 10.2 |
| | 33 | 29.2 | 0.096 | 10.2 | 14.9 | 6.80 | 10.82 | 18.7 |
| | 34 | 40.5 | 0.096 | 10.2 | 14.9 | 15.13 | 23.83 | 29.8 |
| | 35 | 49.8 | 0.096 | 10.2 | 14.9 | 26.63 | 41.50 | 42.4 |
| XII.. | 36 | 10.0 | 0.087 | 10.2 | 14.9 | 0.57 | 0.92 | 4.4 |
| | 37 | 20.1 | 0.087 | 10.2 | 14.9 | 3.15 | 5.04 | 12.2 |
| | 38 | 30.6 | 0.087 | 10.2 | 14.9 | 8.25 | 13.10 | 20.7 |
| | 39 | 40.0 | 0.087 | 10.2 | 14.9 | 16.32 | 25.69 | 31.1 |
| | 40 | 50.2 | 0.087 | 10.2 | 14.9 | 29.42 | 36.36 | 44.0 |

## DISCUSSION.

*Digest.*—Our present purpose will be greatly facilitated by a tabular comparison of the essential features of the results in hand. The following digest (Tables 54 to 59) contains, besides brief descriptions of temper, the hardness as represented by the specific resistance $s$, together with the corresponding magnetic moments per unit of mass, $m$, of the several rods.

TABLE 54.—*Rod I.*

| Description of temper. | Hardness, $s$. | Specific magnetism, $m$. | | | |
|---|---|---|---|---|---|
| | | No. 1. | No. 2. | No. 3. | No. 4 |
| Glass-hard | 38.5 | 33.7 | 43.0 | 45.0 | 47.1 |
| Annealed 1 hour in steam 100° | 36.3 | 33.3 | 42.0 | 44.3 | 46.5 |
| Annealed 3 hours in steam 100° | 34.8 | 32.7 | 41.0 | 43.3 | 45.1 |
| Annealed 6 hours in steam 100° | 33.9 | 32.2 | 40.1 | 42.7 | 45.1 |
| Annealed 10 hours in steam 100° | 33.4 | 32.1 | 40.2 | 42.7 | 45.1 |
| Annealed 20 minutes in aniline vapor 185° | 29.5 | 32.2 | 42.8 | 45.9 | 48.9 |
| Annealed 1 hour in aniline vapor 185° | 28.4 | 34.1 | 45.1 | 48.1 | 51.5 |
| Annealed 3 hours in aniline vapor 185° | 27.1 | 36.1 | 48.8 | 52.6 | 56.4 |
| Annealed 7 hours in aniline vapor 185° | 25.9 | 37.9 | 53.3 | 57.3 | 61.6 |
| Annealed 13 hours in aniline vapor 185° | 25.0 | 39.9 | 57.1 | 61.3 | 65.4 |
| Annealed 1 minute in lead bath 330° | 20.4 | 39.4 | 70.5 | 80.5 | 87.0 |
| Annealed 1 hour in lead bath 330° | 18.8 | 36.3 | 74.0 | 86.4 | 95.1 |
| Soft | 15.7 | 8.0 | 31.9 | 53.0 | 67.4 |

TABLE 55.—*Rod II.*

| Description of temper. | Hardness, $s$. | Specific magnetism, $m$. | | | | | |
|---|---|---|---|---|---|---|---|
| | | No. 5. | No. 6. | No. 7. | No. 8. | No. 9. | No. 10 |
| Glass-hard | 37.3 | ..... | 43.9 | ..... | ..... | 53.5 | 58.1 |
| Annealed 1 hour in steam 100° | 34.7 | ..... | 43.1 | ..... | ..... | 52.8 | 58.1 |
| Annealed 3 hours in steam 100° | 33.0 | ..... | 42.5 | ..... | ..... | 51.8 | 57.1 |
| Annealed 6 hours in steam 100° | 32.2 | ..... | 42.0 | ..... | ..... | 50.8 | 57.2 |
| Annealed 10 hours in steam 100° | 31.6 | 29.6 | 41.1 | 46.4 | 47.8 | 51.0 | ..... |
| Annealed 20 minutes in aniline vapor 185° | 27.4 | 29.1 | 43.6 | 48.9 | 51.3 | 55.0 | ..... |
| Annealed 1 hour in aniline vapor 185° | 26.3 | 30.0 | 45.6 | 51.5 | 53.7 | 58.0 | ..... |
| Annealed 3 hours in aniline vapor 185° | 24.9 | 31.8 | 49.3 | 55.9 | 58.2 | 63.1 | ..... |
| Annealed 7 hours in aniline vapor 185° | 23.7 | 34.7 | 53.0 | 61.0 | 64.0 | 69.0 | ..... |
| Annealed 13 hours in aniline vapor 185° | 22.8 | 35.2 | 56.2 | 65.1 | 69.1 | 73.1 | ..... |
| Annealed 1 minute in lead bath 330° | 18.9 | 31.5 | 60.9 | 78.5 | 84.0 | 94.0 | ..... |
| Annealed 1 hour in lead bath 330° | 17.4 | 29.8 | 61.1 | 82.5 | 89.8 | 102.6 | ..... |
| Soft | 14.5 | 8.7 | 23.7 | 45.7 | 54.7 | 80.7 | ..... |

TABLE 56.—*Rod IX.*

| Description of temper. | Hardness, $s$. | Specific magnetism $m$, for the dimension-ratio= | | | | |
|---|---|---|---|---|---|---|
| | | 9.9 | 20.0 | 30.6 | 41.1 | 51.2 |
| Glass-hard | 47.2 | 22.7 | 35.8 | 41.4 | 44.0 | 46.0 |
| Annealed 1 hour in steam 100° | 42.0 | 21.2 | 33.6 | 38.8 | 41.3 | 43.2 |
| Annealed 3 hours in steam 100° | 39.5 | 21.4 | 33.2 | 38.2 | 40.6 | 42.3 |
| Annealed 6 hours in steam 100° | 38.2 | 21.6 | 33.2 | 38.2 | 40.4 | 42.1 |
| Annealed 10 hours in steam 100° | 37.4 | 21.5 | 33.3 | 38.2 | 40.5 | 42.2 |
| Annealed 20 minutes in aniline vapor 185° | 31.5 | 20.2 | 34.3 | 40.7 | 43.6 | 45.8 |
| Annealed 1 hour in aniline vapor 185° | 29.7 | 20.4 | 35.7 | 42.9 | 46.1 | 48.6 |
| Annealed 3 hours in aniline vapor 185° | 27.9 | 21.0 | 38.7 | 47.2 | 51.0 | 53.8 |
| Annealed 7 hours in aniline vapor 185° | 26.2 | 22.1 | 42.2 | 52.2 | 57.0 | 60.5 |
| Annealed 13 hours in aniline vapor 185° | 24.8 | 21.8 | 44.1 | 56.0 | 61.9 | 65.8 |
| Annealed 10 minutes in tin bath 240° | 24.0 | 21.5 | 44.6 | 57.5 | 63.8 | 68.5 |
| Annealed 1 minute in lead bath 330° | 20.3 | 19.7 | 46.8 | 67.0 | 79.2 | 85.8 |
| Annealed 1 hour in zinc bath 420° | 17.5 | 16.2 | 43.7 | 72.5 | 90.5 | 100.7 |
| Soft | 15.7 | 4.5 | 11.7 | 22.1 | 34.8 | 46.5 |

TABLE 57.—*Rod X.*

| Description of temper. | Hardness, *s*. | Specific magnetism *m*, for the dimension-ratio= | | | | |
|---|---|---|---|---|---|---|
| | | 9.8 | 19.6 | 30.1 | 40.2 | 50.7 |
| Glass-hard | 46.8 | 23.3 | 36.8 | 42.4 | 44.8 | 46.4 |
| Annealed 1 hour in steam 100° | 41.7 | 22.0 | 34.4 | 39.9 | 42.1 | 43.6 |
| Annealed 3 hours in steam 100° | 39.3 | 22.4 | 34.0 | 39.2 | 41.2 | 42.6 |
| Annealed 6 hours in steam 100° | 38.0 | 22.4 | 34.0 | 38.9 | 41.0 | 42.5 |
| Annealed 10 hours in steam 100° | 37.1 | 22.4 | 33.9 | 39.0 | 41.1 | 42.5 |
| Annealed 20 minutes in aniline vapor 185° | 31.4 | 21.5 | 35.0 | 41.5 | 44.4 | 46.1 |
| Annealed 1 hour in aniline vapor 185° | 29.6 | 20.9 | 36.4 | 43.7 | 47.1 | 49.1 |
| Annealed 3 hours in aniline vapor 185° | 27.7 | 21.7 | 39.6 | 48.5 | 52.4 | 54.7 |
| Annealed 7 hours in aniline vapor 185° | 26.0 | 22.2 | 42.9 | 58.8 | 58.5 | 61.4 |
| Annealed 13 hours in aniline vapor 185° | 24.6 | 21.9 | 44.7 | 57.9 | 63.6 | 67.0 |
| Annealed 10 minutes in tin bath 240° | 23.8 | 21.5 | 45.5 | 59.7 | 66.1 | 69.8 |
| Annealed 1 minute in lead bath 330° | 20.1 | 19.3 | 46.2 | 67.9 | 80.0 | 86.5 |
| Annealed 1 hour in zinc bath 420° | 17.2 | 15.2 | 40.7 | 72.1 | 91.9 | 101.5 |
| Soft | 15.6 | 3.8 | 10.5 | 20.3 | 31.4 | 45.4 |

TABE 58.—*Rod XI.*

| Description of temper. | Hardness, *s*. | Specific magnetism *m*, for the dimension-ratio= | | | | |
|---|---|---|---|---|---|---|
| | | 9.9 | 20.3 | 29.2 | 40.5 | 49.8 |
| Glass-hard | 42.8 | 24.8 | 41.0 | 47.2 | 50.8 | 52.5 |
| Annealed 1 hour in steam 100° | 38.6 | 23.3 | 39.2 | 45.2 | 48.7 | 50.4 |
| Annealed 3 hours in steam 100° | 36.5 | 23.4 | 38.6 | 44.5 | 47.7 | 49.3 |
| Annealed 6 hours in steam 100° | 35.1 | 23.3 | 38.6 | 44.3 | 47.4 | 49.1 |
| Annealed 10 hours in steam 100° | 34.3 | 23.3 | 38.3 | 44.2 | 47.4 | 48.9 |
| Annealed 20 minutes in aniline vapor 185° | 29.0 | 21.0 | 38.9 | 46.0 | 50.3 | 52.3 |
| Annealed 1 hour in aniline vapor 185° | 27.5 | 21.3 | 40.2 | 48.1 | 52.9 | 55.1 |
| Annealed 3 hours in aniline vapor 185° | 25.6 | 21.6 | 42.7 | 52.2 | 57.7 | 60.2 |
| Annealed 7 hours in aniline vapor 185° | 24.2 | 21.8 | 45.5 | 56.9 | 63.5 | 66.8 |
| Annealed 13 hours in aniline vapor 185° | 22.9 | 20.9 | 46.2 | 59.7 | 68.1 | 71.8 |
| Annealed 10 minutes in tin bath 240° | 22.2 | 20.4 | 46.7 | 61.0 | 70.2 | 74.3 |
| Annealed 1 minute in lead bath 330° | 19.0 | 19.0 | 46.7 | 68.0 | 83.7 | 90.0 |
| Annealed 1 hour in zinc bath 420° | 16.2 | 14.4 | 40.1 | 72.6 | 93.9 | 103.9 |
| Soft | 14.9 | 4.3 | 10.2 | 18.7 | 29.8 | 42.4 |

TABLE 59.—*Rod XII.*

| Description of temper. | Hardness, *s*. | Specific magnetism *m*, for the dimension-ratio= | | | | |
|---|---|---|---|---|---|---|
| | | 10.0 | 20.1 | 30.6 | 40.0 | 50.2 |
| Glass-hard | 43.5 | 23.0 | 36.9 | 43.4 | 46.3 | 48.3 |
| Annealed 1 hour in steam 100° | 38.4 | 22.1 | 35.6 | 41.8 | 44.6 | 46.6 |
| Annealed 3 hours in steam 100° | 36.2 | 22.2 | 35.3 | 41.3 | 43.9 | 45.7 |
| Annealed 6 hours in steam 100° | 34.9 | 21.9 | 35.3 | 41.1 | 43.6 | 45.5 |
| Annealed 10 hours in steam 100° | 34.0 | 22.2 | 35.2 | 40.9 | 43.5 | 45.4 |
| Annealed 20 minutes in aniline vapor 185° | 28.7 | 20.6 | 35.9 | 43.4 | 46.7 | 49.0 |
| Annealed 1 hour in aniline vapor 185° | 27.3 | 20.5 | 37.2 | 45.6 | 49.3 | 51.8 |
| Annealed 3 hours in aniline vapor 185° | 25.5 | 21.2 | 39.8 | 49.6 | 54.0 | 57.1 |
| Annealed 7 hours in aniline vapor 185° | 23.9 | 21.6 | 42.6 | 54.4 | 59.6 | 63.4 |
| Annealed 13 hours in aniline vapor 185° | 22.7 | 21.1 | 43.8 | 57.4 | 63.8 | 68.2 |
| Annealed 10 minutes in tin-bath 240° | 22.0 | 20.7 | 44.0 | 58.8 | 65.8 | 70.8 |
| Annealed 1 minute in lead-bath 330° | 18.7 | 19.0 | 43.3 | 65.0 | 78.8 | 86.8 |
| Annealed 1 hour in zinc-bath 420° | 16.0 | 14.9 | 38.5 | 68.0 | 89.0 | 101.1 |
| Soft | 14.9 | 4.4 | 12.2 | 20.7 | 31.1 | 44.0 |

*Plan of the discussion.*—These results may be discussed from two distinct stand-points. In case of one and the same wire, the specific magnetism of the magnets taken out of it varies both with their degree

of hardness and with the ratio of length and diameter. In place of a diagram in three dimensions, however, it is expedient to regard the one or the other variable, as an arbitrary constant, while the other passes through all possible values. We thus represent all relations by plane diagrams. Our results are compared in this way. It is, however, convenient to replace Tables 54 and 55 by others satisfactorily deducible from them by graphic interpolation, since the ratio of dimensions in the earlier experiments (Tables 54 and 55) do not compare well with those in the later (Tables 56 to 59). In other words, without such reconstruction of the former results, the difference of magnetic behavior of the two kinds of steel employed cannot be readily discerned. For this reason the Tables 60 and 61, following, have been prepared. The data contained are such as would have been found if the ratio of dimensions had been $\alpha=20$, 40, 60, 80, and 100, respectively, in place of the values which actually obtained.

TABLE 60.—*Rod I.*

| Description of temper. | Hardness, $s$. | Specific magnetism $m$, for the dimension-ratio= | | | | |
|---|---|---|---|---|---|---|
| | | 20 | 40 | 60 | 80 | 100 |
| Glass-hard | 38.5 | 31.4 | 40.2 | 44.3 | 46.5 | 48.0 |
| Annealed 1 hour in steam 100° | 36.3 | 30.5 | 39.2 | 42.9 | 44.7 | 46.0 |
| Annealed 3 hours in steam 100° | 34.8 | 30.1 | 38.5 | 42.2 | 43.9 | 45.2 |
| Annealed 6 hours in steam 100° | 33.9 | 29.9 | 38.3 | 42.0 | 43.8 | 45.0 |
| Annealed 10 hours in steam 100° | 33.4 | 29.8 | 38.0 | 41.8 | 43.8 | 45.2 |
| Annealed 20 minutes in aniline vapor 185° | 29.5 | 29.6 | 40.0 | 44.5 | 47.2 | 48.4 |
| Annealed 1 hour in aniline vapor 185° | 28.4 | 30.3 | 42.3 | 47.4 | 50.3 | 52.2 |
| Annealed 3 hours in aniline vapor 185° | 27.1 | 31.8 | 46.2 | 51.6 | 54.4 | 56.5 |
| Annealed 7 hours in aniline vapor 185° | 25.9 | 33.6 | 50.4 | 56.0 | 59.1 | 61.4 |
| Annealed 13 hours in aniline vapor 185° | 25.0 | 34.7 | 52.6 | 60.0 | 63.4 | 65.8 |
| Annealed 1 minute in lead-bath 330° | 20.4 | 32.2 | 63.4 | 77.3 | 84.2 | 88.2 |
| Annealed 1 hour in lead-bath 330° | 18.8 | 26.0 | 65.3 | 81.4 | 90.3 | 97.3 |
| Soft | 15.7 | 6.0 | 21.3 | 43.0 | 59.4 | 70.3 |

TABLE 61.—*Rod II.*

| Description of temper. | Hardness, $s$. | Specific magnetism $m$, for the dimension-ratio= | | | | |
|---|---|---|---|---|---|---|
| | | 20 | 40 | 60 | 80 | 100 |
| Glass-hard | 37.3 | 31.5 | 45.0 | 49.5 | 51.3 | 52.4 |
| Annealed 1 hour in steam 100° | 34.7 | 30.4 | 43.4 | 47.8 | 49.7 | 50.5 |
| Annealed 3 hours in steam 100° | 33.0 | 30.0 | 42.8 | 47.3 | 49.0 | 49.9 |
| Annealed 6 hours in steam 100° | 32.2 | 29.9 | 42.7 | 47.2 | 48.8 | 49.8 |
| Annealed 10 hours in steam 100° | 31.6 | 29.9 | 42.7 | 47.2 | 48.8 | 49.7 |
| Annealed 20 minutes in aniline vapor 185° | 27.4 | 29.4 | 45.8 | 50.1 | 52.5 | 54.0 |
| Annealed 1 hour in aniline vapor 185° | 26.3 | 30.0 | 47.3 | 52.2 | 55.0 | 56.6 |
| Annealed 3 hours in aniline vapor 185° | 24.9 | 32.8 | 50.9 | 57.3 | 60.0 | 62.2 |
| Annealed 7 hours in aniline vapor 185° | 23.7 | 34.3 | 54.7 | 62.3 | 66.0 | 68.6 |
| Annealed 13 hours in aniline vapor 185° | 22.8 | 35.0 | 58.0 | 66.4 | 70.8 | 73.6 |
| Annealed 1 minute in lead-bath 330° | 18.9 | 33.0 | 64.3 | 80.7 | 88.6 | 92.3 |
| Annealed 1 hour in lead-bath 330° | 17.4 | 30.0 | 65.3 | 84.6 | 95.0 | 100.8 |
| Soft | 14.5 | 6.0 | 27.8 | 47.5 | 63.3 | 74.0 |

*General inferences.*—A detailed comparison of the results expressed in Tables 60 and 61 with those in Tables 53, 57, 58, 59, and all of these among themselves, shows conclusively that the magnetic behavior of

each particular wire is of a distinct and individual character. More perspicuously, even, the same fact is observable in a graphic representation of the data. The curves obtained for the several wires are by no means coincident. The thicker wire shows greater magnetizability than the wire of smaller diameter. In the case of both kinds of steel, galvanically hard rods are magnetizable to a lesser degree than soft rods. Moreover, there appears to exist a relation between the density and maximum permanent moment, in so far as the latter in general increases directly with the former. This effect is particularly apparent for the thicker wire. But the fundamental inference is this, that the relation between specific magnetism and hardness expressed galvanically, as exhibited by all the wires, is essentially of the same kind.

*Magnetism and hardness.*—The general contours of the families of curves expressing the functionality between magnetic moment, per unit of mass, hardness, ratio of dimensions, are of very great interest. It appears clearly that the latter variable by no means deserves the exclusive importance which has hitherto been attributed to it, at least not in the accepted sense that a certain critical value exists (Ruths, for instance, puts it, $\alpha=35$) below which magnets differ in a pronounced way as regards magnetizability, from magnets with a larger dimension-ratio. The variations of the series of curves belonging to magnets taken from one and the same wire are obviously of like nature; in other words, obtained from a definite law by the mere change of a parametric constant, $a$. In general, all magnets, whether long or short, after incipient annealing diminish in magnetizability, until a well-marked minimum of this quality is reached. If thereafter annealing be continued magnetizability again increases, attains a maximum, and finally decreases again to the value for the soft state.

The causes which led earlier observers into partially erroneous inferences are not far to seek. With the ordinary very rough method of estimating the degree of hardness of steel by the aid of the oxide tints, the character of the curves, as a whole, did not appear. Hitherto data for only four points for each rod, corresponding to the hard, the yellow, the blue, and the soft states, were available. Irrespective of the vagueness of degrees of hardness thus defined it will readily be seen that where the full contours of the curves are unknown the grouping of these points is such as to suggest the said imperfect inference of a critical dimension-ratio.

The effect of a variation of dimensions is particularly apparent in its bearing on the position and value of the minima and maxima of the permanently saturated magnetic state. In proportion as the length of the magnets, or more accurately the ratio of dimensions increases, these singular points, which are nearly coincident in very short rods, move apart, the minimum occurring in the glass-hard state, the maximum passing at a very rapid rate toward the soft state. At the same time the maximum increases enormously in value, and for long, thin rods in

greater than twice the equivalent of the permanently saturated magnetic moment of the same rod when hard. As we approach short rods, as will be seen, the maximum flattens out, moving toward the minimum at a more rapid rate than the minimum progresses in the opposite direction. But the variations are such that for very short magnets, i. e., such for which the ratio of dimensions is below 5, the minimum will probably lose its marked character altogether, and eventually come into full coincidence with the maximum. Here, therefore, a uniformly continuous decrease of magnetizability from the glass-hard to the soft states is to be anticipated.

*Graphic representation.*—All these results may be made to appear with striking clearness by representing them graphically. It will be sufficient for this purpose to accept the mean of the two series of results for the thin sample of steel wire, and then to compare this with the mean or combined results (four series) obtaining for the thicker sample of wire. These mean values are given in the following tables, 62 and 63:

TABLE 62.—*Progressive states of magnetizability, varying with hardness.*

[Thick wire, $2\rho$=0.15 centimeter.]

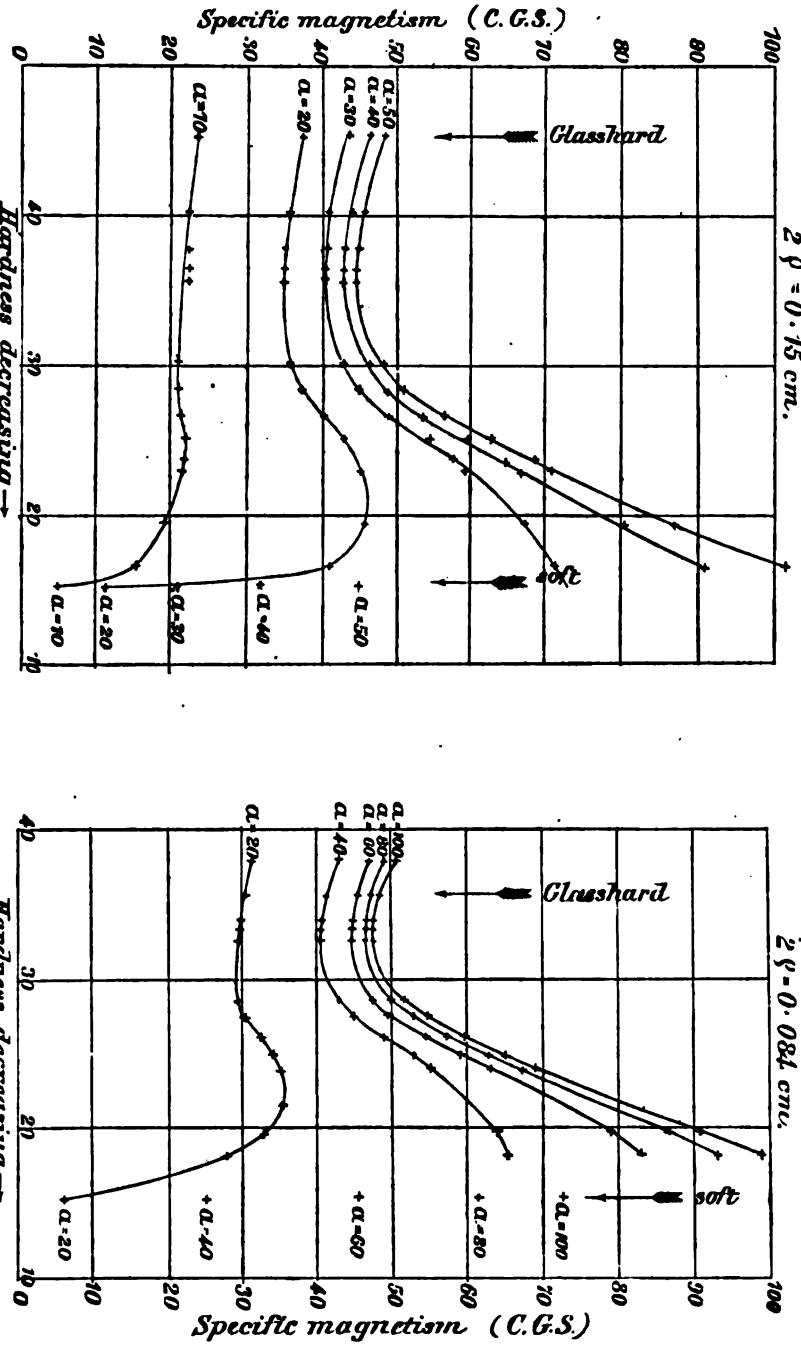
| Mean hardness (galvan). | Mean specific magnetism $m$, for the dimension-ratio = | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| 45.3 | 23.5 | 37.6 | 43.6 | 46.5 | 48.3 |
| 40.2 | 22.2 | 35.7 | 41.3 | 44.2 | 46.0 |
| 37.9 | 22.3 | 35.3 | 40.8 | 43.3 | 45.0 |
| 36.6 | 22.3 | 35.3 | 40.6 | 43.1 | 44.8 |
| 35.7 | 22.3 | 35.2 | 40.6 | 43.1 | 44.8 |
| 30.2 | 20.8 | 36.0 | 42.9 | 46.2 | 48.3 |
| 28.5 | 20.8 | 37.4 | 45.1 | 48.8 | 51.2 |
| 26.7 | 21.4 | 40.2 | 49.4 | 53.8 | 56.5 |
| 25.1 | 21.9 | 43.3 | 54.3 | 59.6 | 63.0 |
| 23.8 | 21.4 | 44.7 | 57.8 | 64.3 | 68.2 |
| 22.0 | 21.0 | 45.2 | 59.3 | 66.5 | 70.9 |
| 19.5 | 19.3 | 45.8 | 67.0 | 80.4 | 87.3 |
| 16.7 | 15.2 | 40.8 | 71.3 | 91.3 | 101.8 |
| 15.3 | 4.3 | 11.2 | 20.5 | 31.8 | 44.6 |

TABLE 63.—*Progressive states of magnetizability, varying with hardness.*

[Thin wire, $2\rho$=0.084 centimeter.]

| Mean hardness (galvan). | Mean specific magnetism $m$, for the dimension-ratio = | | | | |
|---|---|---|---|---|---|
| | 20 | 40 | 60 | 80 | 100 |
| 37.9 | 31.5 | 42.6 | 46.9 | 48.9 | 50.2 |
| 35.5 | 30.5 | 41.3 | 45.4 | 47.2 | 48.3 |
| 33.9 | 30.1 | 40.7 | 44.8 | 46.5 | 47.6 |
| 33.1 | 29.9 | 40.5 | 44.6 | 46.3 | 47.4 |
| 32.5 | 29.8 | 40.3 | 44.5 | 46.3 | 47.4 |
| 28.5 | 29.5 | 42.6 | 47.3 | 49.8 | 51.7 |
| 27.4 | 30.1 | 44.8 | 49.8 | 52.7 | 54.5 |
| 26.0 | 32.3 | 48.6 | 54.4 | 57.2 | 59.4 |
| 24.8 | 33.9 | 52.6 | 59.2 | 62.6 | 64.7 |
| 23.9 | 34.8 | 55.3 | 63.2 | 67.1 | 69.9 |
| 19.7 | 32.6 | 63.8 | 79.0 | 86.4 | 92.7 |
| 18.1 | 28.0 | 65.3 | 83.0 | 92.7 | 98.0 |
| 15.1 | 6.0 | 24.5 | 45.3 | 61.4 | 72.2 |

On the basis of these tables the two families of curves, Figs. 17 and 18, have been constructed.




FIGS. 17 and 18.—Relation between specific magnetism and hardness of steel for different dimension-ratios.

*Magnetism and dimension-ratio.*—Of equally great interest, moreover, is the other phase of these phenomena in which magnetizability is regarded as a function of the independent variable, the dimension-ratio, whereas hardness appears merely as an arbitrary constant. We will endeavor in this place to give an account of our data, sufficiently detailed to admit satisfactorily of a comparison with results of earlier observers. In the absence of a better means of estimating hardness the oxide tints were largely made use of, and the wires examined, therefore, classified as hard, yellow annealed, blue annealed, and soft. In conformity with this method of description, we will attempt to give the parameter (hardness) in our own results, such values as will correspond with the said four States. The following special experiments furnish approximate data for the expression of the degree of hardness corresponding to any given oxide tint in our own galvanic scale:

| | Cm / Cm², 0° microhm. |
|---|---|
| Glass-hard | s=45.7 |
| Yellow annealed | s=26.3 |
| Blue annealed | s=20.5 |
| Soft | s=15.9 |

It is well to note that the logarithmic interval between yellow annealed and blue annealed is about equivalent to the same interval between blue annealed and soft, and about twice as large as that between glass-hard and yellow annealed. Referred to our method of tempering, the values for yellow annealed and blue annealed would agree very nearly with three hours of annealing in aniline vapor (mean s=26.7 and 26.0) and one minute of annealing in melting lead (mean s=19.5 and 19.7), respectively.

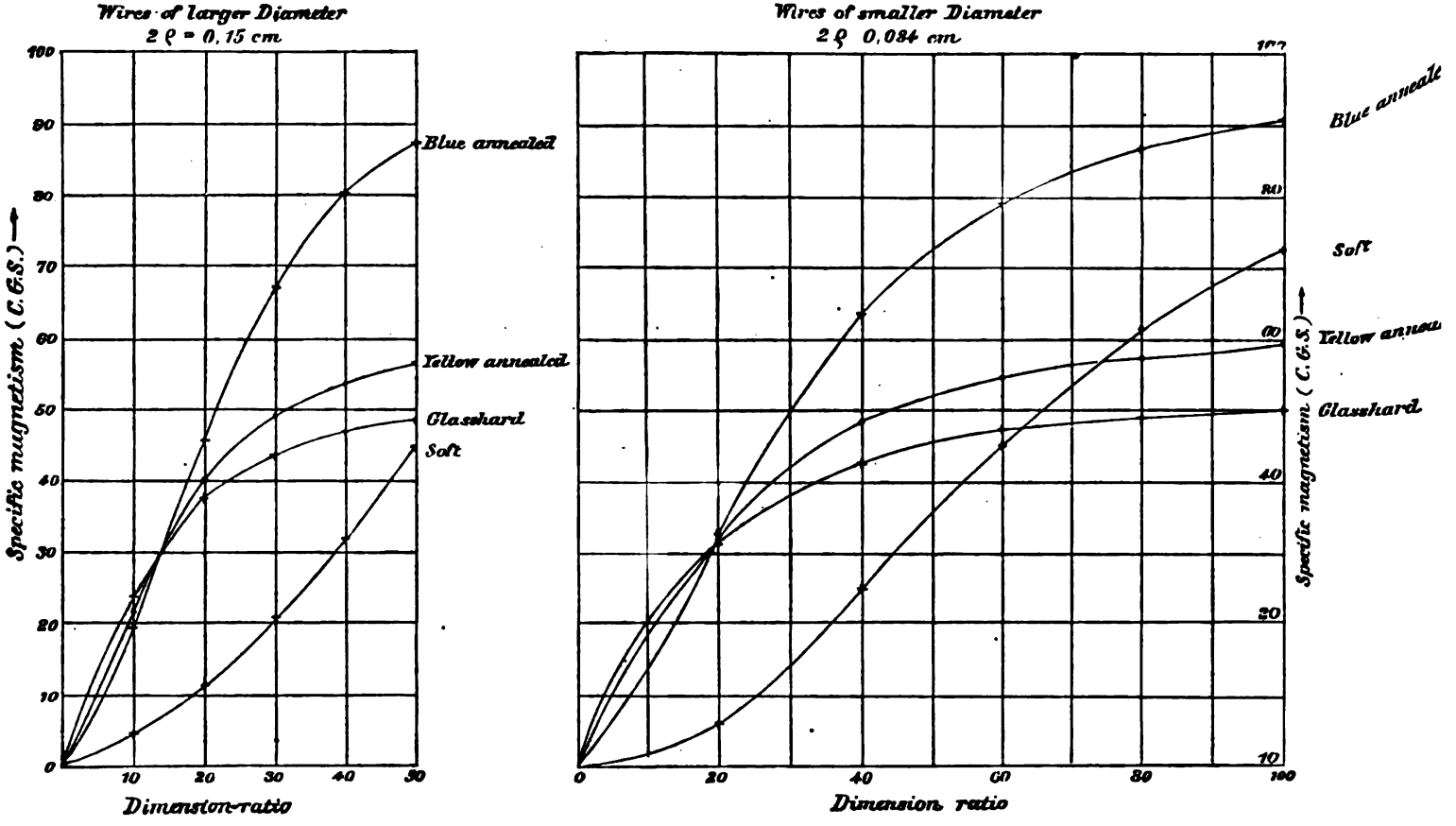
The smaller galvanic values for these states correspond to the smaller values for the soft state (mean s=15.3 and 15.1), respectively, and the difference is, therefore, obviously due to carburation. Hence for our present purposes it is fully sufficient to select from tables 62 and 63 the following mean values of magnetism for the degrees of hardness in question:

TABLE 64.—*Thick wire.*

| | Mean specific magnetism m, for the dimension-ratio = | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| Glass-hard | 23.5 | 37.6 | 43.6 | 46.5 | 48.3 |
| Yellow annealed | 21.4 | 40.2 | 49.4 | 53.8 | 56.5 |
| Blue annealed | 10.3 | 45.8 | 67.0 | 80.4 | 87.3 |
| Soft | 4.3 | 11.2 | 20.5 | 31.8 | 44.6 |

TABLE 65.—*Thin wire.*

| | Mean specific magnetism m, for the dimension-ratio = | | | | |
|---|---|---|---|---|---|
| | 20 | 40 | 60 | 80 | 100 |
| Glass-hard | 31.5 | 42.6 | 46.9 | 48.9 | 50.2 |
| Yellow annealed | 32.3 | 48.6 | 54.4 | 57.2 | 58.4 |
| Blue annealed | 32.6 | 63.8 | 79.0 | 88.4 | 93.7 |
| Soft | 6.0 | 24.5 | 45.3 | 61.4 | 72.3 |




FIGS. 19 and 20.—Relation between specific magnetism and dimension-ratio of steel rods, for different degrees of hardness.

*Graphic representation.*—These data enable us to construct the curves in Figs. 19 and 20.

The curve glass-hard is concave as regards the axis of abscissæ throughout. Rising very rapidly at first it finally ascends to a distinct limiting value or horizontal asymptote. The curve soft, on the other hand, rises very slowly in its earlier stages, and is convex as regards the axis of abscissæ. From here it passes rapidly upward through a point of circumflexion into concavity towards X, and then above the former curve. Finally the rate of ascent again decreases so that a horizontal asymptote must eventually also be reached, but apparently at a later stage of the progress than is the case with hard wire. From either of these two curves, which describe the variations of the extreme states, we may, by the process of annealing, pass continuously to the other; but the manner of such passage from the one to the other, resulting from a continuous change of parameter (hardness), is excessively complicated. Incipient annealing of a glass-hard rod produces a distinct though small descent of the original curve as a whole. As annealing progresses, the farther end of the curve is always the first to rise and pass above the original curve in such a way that the point of intersection of the new curve and the original curve, glass-hard, moves rapidly from greater to smaller values of the dimension-ratio. When the curve "yellow annealed" is reached the part between $\alpha=14$ or 18, respectively, and $\alpha=\infty$ has already been elevated above the curve glass-hard. In the case of the "blue annealed" curve we observe the part between $\alpha=15$ or 20, respectively, and $\alpha=\infty$ to have risen enormously; but on the other hand the part of this curve between $\alpha=0$ and $\alpha=15$ or 20, respectively, having descended gradually, is now distinctly convex as regards the axis of abscissæ. Passing from blue-annealed to soft, we find the left-hand part of the curve falling at a more rapid rate, while the right-hand branch still rises slowly, reaching a superior limit and then falling rapidly into coincidence with the curve for the soft state, already discussed.

We have remarked that the phenomenon of variation of magnetizability, regarded as a whole, does not by any means seem to present a certain critical value for the dimension-ratio, below which magnets behave differently than above it. If only the four curves hard, yellow annealed, blue annealed and soft were known, as they appear in Figs. 19 and 20, there would appear to be reasons for considering $\alpha=15$ or 20, respectively, as a critical value of this kind; for it is here that the three curves approximately intersect each other. How unjustifiable, however, such conclusions are, will be obvious from a mere glance at Figs. 17 and 18, in which the curves for this value of $\alpha$ manifest no change of character whatever.

*Magnetism and density.*—We may remark here that when the rod is very long in comparison with its diameter, its specific magnetism (saturation presupposed) becomes constant or independent of the dimensions.

In Green's equation for the distribution of magnetism in a cylinder of finite length, $2l$, and radius $r$.

$$\lambda = \pi KX \operatorname{pr} \frac{e^{\frac{\pi l}{r}} - e^{-\frac{\pi l}{r}}}{e^{\frac{\pi l}{r}} + e^{-\frac{\pi l}{r}}}$$

where $\lambda$ is the linear density of free magnetism at a distance $x$ from the middle of the cylinder, $K$ the coefficient of magnetization, $X$ the magnetizing force, $p$ a numerical quantity related to $K$; let $KX$ be accepted as the expression for coercive force, $F$, and put for greater simplicity

$$r \, lg \frac{1}{\nu} = p.$$

If now we evaluate

$$M = 2 \int_0^l \lambda x dx = -\frac{2 \pi p F r}{lg \nu} \left[ l + \frac{1}{lg \nu} \frac{\nu^{-1} - \nu^{+1}}{\nu^{-1} + \nu^{+1}} \right]$$

and furthermore put

$$m = \frac{M}{\mu} = \frac{M}{\pi r^2 l d}$$

we find that if $l$ (or better $\frac{l}{r} = \alpha$) be supposed to increase indefinitely, $m$ will pass through

$$m = \frac{2F}{d} \left\{ 1 - \frac{1}{p \alpha} \right\}$$

into a constant value, depending only on the material. Biot[132] put $p = 0.124$, approximately.

Now it is remarkable that in this case, in which moreover the expression for the linear distribution of magnetism attains its simplest form, we are led to infer that the (linear) rods are capable of retaining more magnetism permanently in proportion as they are softer. But this general deduction will not hold good as far as the soft state. Figure 20 gives as yet no decisive answer to this question. However, in passing from the blue annealed to the soft condition, steel passes through a state of maximum density; and our results thus give warrant to the surmise that the greatest attainable magnetization can be imparted to steel, when the hardness of the necessarily linear rod has that particular value which is characterized by maximum density. This digression suggests itself naturally here, but will be made the subject of a special inquiry. From figure 17, however, it is already quite apparent that the said unique maximum will be considerably larger than 785 c. g. s. units of intensity (magnetic moment per unit of volume), the value thus far assumed and derived from an incidental result of Kohlrausch.[133]

[132] Biot: Traité de Phys., III, p. 76, 1816.

[133] Cf. Gordon: Electricity and Magnetism, I, p. 156, London, 1880.

*Earlier results interpreted.*—It will now be in place to compare our results with those of Ruths. We will select from his data the series contained on p. 47 of his memoir, as these may be regarded typical. Here again, those alone can be considered which refer to magnets as nearly as possible in the permanently saturated state. In the place of the absolute magnetic moment of his steel rods we have deduced the corresponding values for specific magnetism from his data. This greatly facilitates comparison.

TABLE 66.—*Ruths' magnetic results.*

Length = 12.

| I. | II. | III. | IV. | V. | VI. | | |
|---|---|---|---|---|---|---|---|
| 0.10 | 0.24 | 0.29 | 0.38 | 0.49 | 0.59 | Diameter. | |
| 70 | 50 | 40 | 30 | 25 | 20 | Dim. ratio, approx. | |
| 1.99 | 4.81 | 6.22 | 10.55 | 17.50 | 25.65 | Mass. | |
| 68.7 | 66.1 | 74.7 | 61 | 66.6 | 51 | Glass-hard. | Spec. Magnetism. |
| 88.6 | 71 | 79.1 | 52 | 38.6 | 29.7 | Yellow annealed. | |
| 92.0 | 71 | 90.2 | 61.3 | 48.2 | 28.4 | Blue annealed. | |

The first comment to be made in this connection has reference to our remarks given in p. 117, on the structural influence of tempering. Ruths' magnets were all of the same lengths, whereas the thickness varied from 0.2 centimeters to 0.6 centimeters. To impart like degrees or similar states of hardness to rods varying in thickness to this very large extent, is manifestly impossible, even if the material were throughout perfectly identical. It follows that the divers values of specific magnetism obtained cannot even be compared one with another. Hence the attempt to arrive at the nature of the functionality between permanent magnetism and ratio of dimensions from these results, must necessarily be futile. Ruths' data are unavailable, therefore, for the construction of curves, corresponding to those in figure 19. We infer from Ruths' table that in general the specific magnetism increases with the dimension-ratio. In the case of the thicker magnets (IV, V, VI) Ruths found values for specific magnetism much larger than our own. In accordance with these, the intersection of the curves glass-hard and blue annealed would occur for $\alpha=30$; the corresponding point for blue annealed and yellow annealed lying at $\alpha=28$. In accordance with Ruths' results, moreover, figure 19 would have to be changed in such a way that the curve glass-hard (to agree with Ruths' large values) rise at a more rapid rate, thus falling short of intersection with the other two curves until these have intersected each other at about $\alpha=20$. Then its passage is through blue annealed at about $\alpha=25$, and through yellow annealed at about $\alpha=40$, where the latter curve is also supposed to rise more rapidly than is the case in our results. But with this apparently satisfactory interpretation, the equivalence of blue annealed and yellow annealed for $\alpha=50$, is wholly in discordance.

Fromme uses eight rods, all of the same length, four of which are of

like small diameter, the other four of like larger diameter, to corroborate Ruths' results. The dimensions are these:

$$\text{First four: } \alpha=\frac{100}{7}=15;\quad \text{second four: } \alpha=\frac{100}{2}=50$$

His results for the ratio of mass ($\mu$) and square of the time ($t$) of vibration are the following:

| | | $\alpha=15$ | $\alpha=50$ |
|---|---|---|---|
| $\mu : t^2$ | Glass-hard | 1962 | 413 |
| | Yellow annealed | 1508 | 448 |
| | Blue annealed | 1118 | 440 |

These values would put the point of intersection of blue annealed and yellow annealed at $\alpha=50$, agreeing with Ruths' result for his magnet II. But this by no means removes the discordance between the data for $\alpha=50$ and those of Ruths for $\alpha<50$, because the latter refer this point to $\alpha=20$.

An extended series of observations on the relation between moment of permanent magnetism and hardness, of exceptional accuracy, has been published by Gray[134] All the rods have the same dimension-ratio, $\alpha=50$. Unfortunately he does not carry one and the same hard rod through all possible states of inferior temper. Although the material is identical throughout, the results are therefore necessarily distorted by structural discrepancies, in addition to the effects due to differences of hardness in the glass-hard state. In operating with low temperatures Mr. Gray neglects the (then unknown) time-effect of annealing.

In Chapter II, pp. 40–43, we discussed the results obtained with rods tempered in a way nearly identical with that employed by Mr. Gray, hard wires being immersed in linseed oil, the temperature of which was raised very gradually by the aid of a Bunsen flame, and batches of wires removed from the bath at different stages of the heating. If we take into consideration the great irregularity of distribution of temper which the rods so treated manifest, the causes of relatively large discrepancies occurring in Mr. Gray's results are apparent at once. For the same reasons we are not able to compare them in detail with our own.

One striking difference between the two sets of results is, however, to be noticed. Mr. Gray has observed no minimum of magnetizability in the region of glass-hardness. The specific magnetism, in general, is found to increase rapidly between glass-hard and annealed at 100°; is fairly constant between the latter state and annealed at about 280°; and after this increases rapidly again until the highest annealing temperature employed (310°) is reached. As a whole, however, the observed range of variation (72 to 80 C. G. S. units of magnetic moment per gramme) is remarkably small when compared with our own (45 to 85

[134] Gray: l. c.

and 42 to 75, respectively, C. G. S. units of magnetic moment per gramme). The following tabular comparison between Mr. Gray's mean results and our own will exhibit this perspicuously:

*Table comparing the mean results of Gray and of B. and S.*

| [Gray. $l$=5.000, $2\rho$=0.097 centimeters.] | | | [B. and S. $l$=7.50 centimeters, $2\rho$=0.15 centimeters.] | | | | |
|---|---|---|---|---|---|---|---|
| Rod. No. — | Annealed at— | Mag. mom. (C. G. S.), per gramme. | Rod No. | Annealed at— | During the time. | Mag. mom. (C. G. S.), per gramme. | Hardness, a |
| 1 to 5 | 15° | 71.82<br>74.33 | | | | | |
| | | | IX to XII | 20° | | 48.3 | 45.3 |
| 6 to 10 | 100° | 75.64<br>76.98 | IX to XII | 100° | 1h | 46.0 | 40.2 |
| | | | IX to XII | 100° | 3h | 45.0 | 37.9 |
| | | | IX to XII | 100° | 6h | 44.8 | 36.6 |
| | | | IX to XII | 100° | 10h | 44.8 | 35.7 |
| 11 to 15 | 150° | 75.60<br>76.50 | | | | | |
| | | | IX to XII | 185° | 20m | 48.3 | 39.2 |
| | | | IX to XII | 185° | 1h | 51.2 | 38.5 |
| | | | IX to XII | 185° | 3h | 56.5 | 38.7 |
| | | | IX to XII | 185° | 7h | 63.0 | 35.1 |
| | | | IX to XII | 185° | 13h | 68.2 | 21.6 |
| 16 to 20 | 200° | 75.76<br>76.04 | | | | | |
| | | | IX to XII | 210° | 10m | 70.9 | 23.6 |
| 21 to 25 | 240° | 77.42 | | | | | |
| 26 to 30 | 250° | 76.89 | | | | | |
| 31 to 35 | 260° | 75.92 | | | | | |
| 36 to 40 | 270° | 77.59 | | | | | |
| 41 to 45 | 280° | 76.51 | | | | | |
| 46 to 50 | 290° | 76.14 | | | | | |
| 51 to 55 | 300° | 78.60<br>79.09 | | | | | |
| 56 to 60 | 310° | 79.24 | | | | | |
| | | | IX to XII | 330° | 1m | 87.3 | 18.5 |
| | | | IX to XII | 440° | 1h | 101.8 | 16.7 |
| | | | IX to XII | 1000° | | 44.6 | 15.3 |

The large though unavoidable discrepancies encountered by Mr. Gray, notwithstanding his careful manipulation and precision of measurement clearly show the difficulties with which the problem in question was then surrounded. We possess no data for the magnetic effect produced by tempering in oil. The only satisfactory method of accounting for the above discordance would be that of supposing that Mr. Gray operated upon a less highly carburized steel than was used in our experiments. In such a case, greater values of specific magnetism for the hard state and small values for the soft state in Mr. Gray's results, as distinguished from our own, are anticipative.

## CONCLUSION.

*The general problem.*—The results in this paper offer only a partial solution of the general problem. Irrespective of the effect of carburation, concerning which remarks have already been made, the temporary and permanent magnetization induced by magnetic fields of an intensity insufficient to saturate steel, are new subjects of importance. A fifth

variable, the intensity of the field, therefore, suggests itself. If we remember how intimately magnetic phenomena are associated with the structural condition of a rod, and how absolutely devoid of reliable facts our knowledge of this actually is, we see how little advancement can be hoped from theory. The mathematical analysis, again, even when starting from the simplified premises of homogeneity, encounters formidable difficulties. On the other hand, the possibility of a solution of the general problem, by the application of the method which we have endeavored to develop in the above, we dare say is undeniable. Such an attack we have in view.

*Practical bearing.*—The present investigation has a practical bearing of some importance. For cylindrical rods it gives a satisfactory solution of the problem as to what degree of hardness is to be chosen in order that a given steel rod may possess the maximum magnetizability. It is a remarkable result, that for very small values of the dimension-ratio considered as one extreme case, the rods can be most intensely magnetized when in the very hard states, whereas for very large values of the dimension-ratio regarded as the other extreme case, similarly favorable conditions are offered by the softer states, with the probability that a state of singular excellence in this respect lies between blue annealed and soft.

But it does not by any means follow herefrom that in the construction of magnets for practical purposes they are to be made glass-hard if short and thick, and soft if long. This question involves elements of quite another character. The problem is so to construct a magnet that with a maximum of intensity it may be best qualified to withstand the hurtful influence of atmospheric changes of temperature, of shocks, and such like effects; in short, to produce a magnet which, under like circumstances, shall always show practically identical values of the intensest available magnetization. This will be made the subject of the next chapter.

## ADDENDUM: ON THE DENSITY-EFFECT OF INCIPIENT ANNEALING OF HARD STEEL.

In Chapter V we adverted to the relation probably existing between the maximum of permanent magnetism of linear steel rods and their density. We there, moreover, state the grounds why the conditions most favorable for the appearance of such a relation are encountered in the case of linear rods. The question is therefore immediately suggested whether the characteristic minimum of magnetizability of steel rods corresponds to an analogously singular point in the variation of density. We commenced experiments with the object of discussing the

matter, with a steel rod 1.91 centimeters in diameter and 5.40 centimeters long, tempered glass-hard in the usual way.

| State of hardness. | Specific gravity at 20°. | Specific volume. |
|---|---|---|
| Commercial | 7.8320 | 1.00000 |
| | 7.8313 | |
| Glass-hard | 7.8035 | 1.00363 |
| | 7.8033 | |
| Annealed 1h at 100° | 7.8032 | 1.00365 |
| Annealed 4h at 100° | 7.8040 | 1.00355 |
| | 7.8039 | |
| Annealed 8h at 100° | 7.8052 | 1.00339 |
| | 7.8052 | |
| Annealed 12h at 100° | 7.8058 | 1.00332 |

The first result obtained from these data is a striking corroboration of a result of Fromme's, viz, that the maximum increase of specific volume experienced by a hard-tempered steel rod diminishes as the diameter of the rod increases. Fromme's results for thickness on specific volume of tempered steel rods are these:

| $2\rho$ = Thickness (cm.) = | 0.7 | 0.42 | 0.265 | 0.255 |
|---|---|---|---|---|
| $v$ = Sp. volume = | 1.00772 | 1.01000 | 1.01285 | 1.01210 |

The result for the above rod $2\rho = 1.91$ and $v = 1.00363$ is in excellent accordance with these data. In drawing this inference it is necessary to bear in mind that serious discrepancies may be introduced by the possible differences in *carburation* of the respective rods. Nevertheless, all these results taken together are so satisfactorily consistent that it is difficult to avoid the deduction made.

The second result shows that the increment of specific volume due to tempering in general decreases as time increases. But this variation takes place at a more rapid rate at the middle stages of the operation than either at its early or closing stages. The curve, therefore, contains a point of circumflection, and the possibility of a maximum near the inception is by no means excluded. To obtain definite and decisive results, however, it will be necessary to operate with thin rods, for which the density effect of tempering is so much more clearly pronounced.

The plausible inference that the anomalous electrical behavior of steel on incipient annealing, discussed in Chapter II (page 67), and the minimum of magnetizability investigated in this chapter, may find an analogous variation in the density of similarly treated hard steel, cannot as yet, therefore, be said to have been disproved.

## CHAPTER VI.

### THE TEMPERING OF STEEL CONSIDERED IN ITS BEARING ON THE POWER OF MAGNETIC RETENTION, OR ON THE CONDITIONS OF MAGNETIC STABILITY OF THIS MATERIAL.

### INTRODUCTION.

*Temporary and permanent magnetic effects of annealing.*—The influence of temperature on the moment of permanent magnetism of steel rods is characterized by a temporary and a permanent effect, usually superimposed. If a steel rod magnetized to saturation at the temperature $t^{\circ}$ is heated to $T^{\circ}$ ($T>t$) and then again cooled to $t^{\circ}$, it will be found to have experienced a loss of magnetic moment. If the process is repeated—the temperatures $t$ and $T$ being the same as before—an additional diminution, decidedly smaller, however, than the first, will manifest itself. Continuing in this way we shall find that the permanent loss converges to zero. The rod is now in a condition for which the magnetization lost during the passage from $t^{\circ}$ to $T^{\circ}$ is again restored when the original temperature $t^{\circ}$ is regained.

Researches on this important subject have been made in great numbers.[135] The result has usually been that magnets which are to be used between the atmospheric temperaturess $t$ and $T$ should be heated and cooled between these or greater limits for an indefinite number of times, in order that a condition of magnetic permanence or of perfect magnetic elasticity, as it has been called, may be assumed.

*Simultaneous mechanical effects hitherto disregarded.*—To the venture of resuming a topic which has been so elaborately and apparently so exhaustively discussed, we were primarily induced by certain new and important facts which our researches on the hardness of steel had developed. Curiously enough among those who operated with glass-hard rods—and it was to these that we, at first, desired to confine our attention—only a few have given even cursory consideration to the important factor, the change of the mechanical state of the material. We have shown that temperatures 20° or 30° above that of the water in which during tem-

[135] The earlier literature is systematized in J. Lamont, Magnetismus, p. 386, 1867; G. Wiedemann, Galvanismus, II a, p. 603, 1874; A. Mousson, Physik, 3 Aufl., III., p. 110. Among the more recent papers (since 1876) we desire to mention: G. Wiedeman, Pogg. Ann., CLVII, p. 257, 1876; J. M. Gaugain, Comptes rend., LXXXII, p. 1422; LXXXIII, p. 661, 1876; LXXXVI, p. 536, 1878; G. Poloni, Beiblätter V, p. 67, p. 802, and p. 614, 1881; Elettricista, II, p. 193, 1878; J. Trowbridge, Am. Journal (3), XXI, p. 316, 1881

pering the rod was chilled, when acting on glass-hard rods can be made to produce annealing effects of definite and accurately definable magnitude.

If, therefore, it is our object to investigate the functionality between magnetization and temperature, it is manifestly necessary at the very outset to exclude all permanent and simultaneous changes in the material carrying the magnetic quality. This is what none of the former observers have done. Temperatures as high as 100° are frequently applied. Under these circumstances the hard rod assumes different mechanical properties while in the hands of the operator, and the results will necessarily be stripped of the claims to accuracy which the care frequently bestowed would otherwise justify.

*Retentiveness.*—There was a second consideration which suggested the present series of experiment. This was the desire to utilize certain earlier data in the endeavor to construct magnets possessing great power of retention. It is not necessary to advert to the important bearing of this problem, not only on all absolute magnetic measurements, but more particularly even on those of a relative character. That the methods now employed are inadequate is conceded by the observers of highest authority and experience. Old magnets subserve best the purposes of measurement; but even these, where a constancy of moment under like circumstances is to be presumed are carefully to be protected from shocks and larger changes of temperature.

*The present work.*—In the following pages our experiments will be cited chronologically. Some of them are merely corroborative as regards results which have already been pronounced by others. But the intimate connection between these and our subject proper, together with the new interpretation which has frequently been given them, vindicates their appearance here.

The method of magnetization and the calculation of the magnetic moment as well as the measurement of hardness was identical with that detailed in Chapter V.

## RETENTIVENESS AS REGARDS VARIATION OF TEMPERATURE.

*Preliminary experiments.*—Our first experiments were incidentally made with six little steel parallelpipedons, of the same material which had been used in a series of experiments described elsewhere. The dimensions (cm.) and mass (*g*) of these, after being tempered to glass-hardness, were as follows:

| | I. | II. | III. | IV. | V. | VI. |
|---|---|---|---|---|---|---|
| Length | 3.0 | 2.5 | 3.0 | 2.5 | 3.0 | 2.5 |
| Breadth | 0.5 | 0.5 | 0.4 | 0.4 | 0.3 | 0.3 |
| Height | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 |
| Mass | 0.328 | 0.278 | 0.278 | 0.232 | 0.183 | 0.113 |

When magnetized with a large Funkler's magnetic battery (50 kilos portative force) of the horseshoe form, these retained the following quantities of specific magnetism:

| | I. | II. | III. | IV. | V. | VI. | |
|---|---|---|---|---|---|---|---|
| $m=$ | 16.4 | 12.9 | 18.6 | 14.8 | 25.0 | 20.7 | $\frac{cm^{\frac{1}{2}}}{gi\ sec}$ |

Hereupon the magnets were transferred from a water-bath at 15° C. to another at 50° C. and then returned. This was repeated ten times, with an allowance of about ten seconds of immersion for each. After this process the respective values of specific magnetism were found to be—

| | I. | II. | III. | IV. | V. | VI. |
|---|---|---|---|---|---|---|
| $m=$ | 16.1 | 12.7 | 18.4 | 14.6 | 24.6 | 20.3 |

The losses are therefore small—as a rule, only about $\frac{1}{2}$ per cent. The temperature 50° appears to be relatively low in so far as its effect in producing the variation in question is concerned. If it should be our purpose to reach a limiting value in this way the operation would have to be repeated a great number of times. Possibly several hundred repetitions would even be inadequate.

For this reason we decided to continue the work with the aid of higher temperatures. The magnets were exposed in steam. Previously, however, we remagnetized them to saturation. This was done with a large and powerful helix, through which the current of a dynamo-electric machine circulated. The mean intensity of the magnetizing force when referred to the lengths 2.5 cm. to 3.0 cm. of the magnets, and for the current 3.0 $cm^{\frac{1}{2}}\ g^{\frac{1}{2}}/sec$, was found to be—

$$\Sigma X = 885\ g^{\frac{1}{2}}/cm^{\frac{1}{2}}\ sec.$$

It is obvious that these powerful forces[136] were far more than sufficient to effect the saturation.

The magnets were now exposed in steam at 100° for consecutive intervals of 20, 40 minutes, then for 1, 2, 3, and finally 4 hours. After each withdrawal from the steam-bath they were laid aside for some time in a room in which the temperature varied between 10° and 15°. After this we made the measurement of the magnetic moment. The

[136] For divers other data relative to this helix conf. Chapter V.

results of this series of experiments are shown in the following table for $m$:

TABLE 67.—*Limits of magnetic state.*

| Description of temper. | I. | II. | III. | IV. | V. | VI. |
|---|---|---|---|---|---|---|
| Original condition (hard) ..... | 18.97 | 14.90 | 21.34 | 17.08 | 28.70 | 23.55 |
| Annealed 20$^m$ in steam 100°..... | 14.08 | 10.74 | 15.80 | 12.42 | 20.94 | 16.66 |
| Annealed 40$^m$ more in steam 100°. | 11.68 | 9.05 | 13.45 | 10.42 | 17.60 | 13.92 |
| Annealed 1$^h$ more in steam 100°... | 10.34 | 8.11 | 12.21 | 9.60 | 15.68 | 12.22 |
| Annealed 2$^h$ more in steam 100°... | 9.42 | 7.32 | 11.21 | 8.85 | 14.16 | 11.04 |
| Annealed 3$^h$ more in steam 100°... | 8.86 | 7.07 | 10.68 | 8.21 | 13.63 | 10.24 |
| Annealed 4$^h$ more in steam 100°... | 8.65 | 6.69 | 10.29 | 8.02 | 12.98 | 9.91 |

If these results be constructed graphically, time of exposure as abscissa and specific magnetism (at ordinary temperature) as ordinate, we obtain a series of curves of regular and similar contour. Their general characteristic is that of an initially rapid descent, which as annealing continues is soon retarded until finally an asymptote parallel to the axis $X$, is approximately reached. These results corroborate the older results for the effect of the time of exposure on the variations of the magnetic state of a bar. The phenomena were first studied by Moser and Riess,[137] somewhat later by Holmgren,[138] and particularly emphasized by the latter in a way at variance to the views of the former observers. Physicists were inclined, however, to refer Holmgren's apparently anomalous results to other causes,[139] whereas Lamont[140] pointed out that Holmgren had operated with glass-hard rods, while the magnets of Moser and Riess were untempered. Quite recently G. Poloni[141] has given the effect of the time of exposure due prominence. He fails, however, clearly to discriminate between the results obtained in cases of differently tempered bars, or, in other words, confounds the effect due to change of temper with the magnetic effect. We shall show in the sequel that they are entirely distinct and can be separately studied.

*Simultaneous magnetic and mechanical effect of annealing.*—But there is another inference of greater relevancy to our immediate inquiry. The curves under consideration are strikingly similar to those formerly obtained while investigating the electrical effect produced by a change of temper of steel (annealing).[142] In fact, the analogy is sufficiently evident to induce us to associate the observed decrement of magnetic intensity and the cotemporaneous change of mechanical state of glass-hard rods as phenomena intrinsically related. In other words, we were inclined to regard annealing as the primary, and the diminution of magnetic intensity (in by far the greater part) as the secondary occurrence; or more

[137] L. Moser and P. Riess: Pogg. Ann., XVII, p. 403, 1829.
[138] K. A. Holmgren: Acta Soc. Scient. Upsala (3) I; Fortschritte d. Physik, p. 536, 1856.
[139] Cf., G. Wiedemann: Galvanismus, II a, p. 614, 1874.
[140] J Lamont: Magnetismus, p. 385, 1867.
[141] G. Poloni: Elletricista, II, p. 139.—Beibl. II, p. 523, 1878.
[142] Strouhal and Barus: Wied. Ann., XI, p. 930, 1880. Chap. II.

curately, to distinguish between a primary or purely magnetic (permanent) effect of temperature, a *direct* effect; and an *indirect* effect of temperature, due to the influence of the rearrangement of molecules in consequence of mechanical annealing, upon the existing intensity of magnetism of the rod.

With the object of verifying this hypothesis we selected a sample out our supply of glass-hard rods which, when tested, showed great uniformity of hardness throughout its length. This was broken into two nearly equal parts Nos. 11 and 12.[143] The constants of each were found to be—

| | No. 11. | No. 12. | |
|---|---|---|---|
| Length ... | 10.0 | 10.0 | cm. |
| Mass..... | 0.417 | 0.418 | *g.* |

These were now magnetized to saturation with the helix, and then annealed in steam at 100° during consecutive intervals of 10, 20, and 30 minutes, 1, 2, 3, 4, 5, and 6 hours. After each of these we made a determination of hardness using specific resistance $s$ at the atmospheric temperature $t$ as a datum for this purpose. Furthermore, in order to arrive at the desired comparison, No. 12 was remagnetized to saturation after each interval of annealing, whereas No. 11 was tested for specific magnetism in the condition in which it left the annealing bath, that is without repeated magnetization.

The results of these experiments are contained in the following table. The specific magnetism is represented by $m^*$ and $m$, according as the magnetic datum in question was obtained with or without remagnetization respectively. W here denotes the observed electrical resistance of the respective rods per meter of length at the temperature $t$, $s$ the corresponding specific resistance (cm./cm.$^2$ 0° microhm).

TABLE 68.—*Diminution of hardness, magnetization, and magnetizability.*

| Description of temper. | Magnet No. 11. | | | | Magnet No. 12. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *W* | *t* | *s* | *m* | *W* | *t* | *s* | *m* | *m** |
| as-hard ..... | 0.755 | 18.3 | 39.5 | 62.6 | 0.761 | 18.5 | 39.9 | ..... | 62.5 |
| nealed 10$^m$ in 100°..... | 741 | 18.7 | 38.7 | 59.5 | 746 | 18.7 | 39.1 | 59.7 | 62.4 |
| nealed+20$^m$ in 100°..... | 724 | 20.1 | 37.6 | 56.0 | 728 | 20.1 | 38.0 | 58.2 | 61.9 |
| nealed+30$^m$ in 100°..... | 708 | 21.0 | 36.7 | 52.6 | 712 | 21.0 | 37.1 | 57.5 | 60.6 |
| nealed+ 1$^h$ in 100° ..... | 689 | 19.9 | 35.7 | 50.0 | 693 | 20.0 | 36.1 | 56.5 | 60.2 |
| nealed+ 2$^h$ in 100°..... | 671 | 20.2 | 34.8 | 47.3 | 676 | 20.1 | 35.2 | 56.1 | 59.5 |
| nealed+ 3$^h$ in 100°..... | 656 | 18.7 | 34.1 | 46.1 | 660 | 18.7 | 34.5 | 56.4 | 59.4 |
| nealed+ 4$^h$ in 100°..... | 646 | 19.2 | 33.5 | 45.1 | 651 | 19.0 | 33.9 | 56.5 | 59.3 |
| nealed+ 5$^h$ in 100°..... | 639 | 20.0 | 33.1 | 44.3 | 644 | 20.0 | 33.5 | 56.3 | 59.1 |
| nealed+ 6$^h$ in 100°..... | 634 | 19.9 | 32.8 | 43.8 | 638 | 19.9 | 33.2 | 56.5 | 59.0 |

[143] The magnets Nos. 1–10, were used in the work detailed in Chapter V.

Mere inspection of this table discovers at once the striking parall in the successive values of specific resistance $s$ and specific magn $m$. If the two series of results be represented graphically, time o posure as abscissa, $s$ and $m$ respectively as ordinate, we obtain 21) two curves of an obviously allied character. Indeed there c

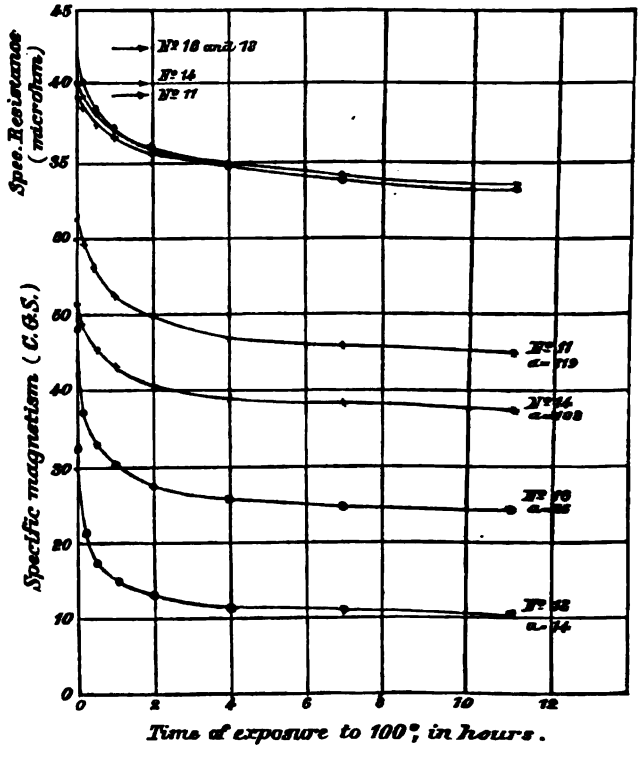



FIG. 21.—Diminution of specific magnetism and specific resistance produced by continued an (low temperatures).

no doubt that the occurrence of the continuous diminution of mag moment here observed is largely conditioned by the variation of t ness which occurs contemporaneously. It is particularly to be n that in both instances the asymptotic limit is reached after the lap the same time, approximately.

If now we regard the values for $m^*$ as obtained with the magnet 12, there appears in the first place a diminution of the quantity of netism which the saturated rod permanently retains, which soon ever, as annealing continues, reaches a certain minimal value in a consistent with the results of the former experiments. Furtherm from a comparison of the values of $m$ and $m^*$, it follows that during progress of the annealing the influence of the higher temperature (10 regarded in connection with the time during which it acts, becomes and less pronounced, in proportion as the magnet itself has reac

ıe limiting state of hardness for the temperature (100°) under consid-ration. But it also appears that the same limiting value of specific ıagnetism gradually reasserts itself, no matter how often the combined rocess of magnetization and subsequent indefinite annealing may be epeated. Moreover, a magnet which has approximately reached the miting hardness for the given temperature, if remagnetized to satura-on and annealed again at the same temperature, reaches a limiting ıagnetic condition, the value of which is nearly independent of the me of exposure.

*The purely magnetic effect (permanent).*—The inference enunciated at ıe end of the last paragraph still needs additional proof. Accordingly, ur magnets Nos. 11 and 12 were now magnetized afresh and then ex-osed to steam in the uniform manner described. We thus arrived at ıe following results:

TABLE 69.—*Specific magnetism, m, of saturated rods successively annealed at* 100°.

| Time of exposure to 100°. | No. 11. | No. 12. |
|---|---|---|
| Rods remagnetized | 59.0 | 59.0 |
| 10 minutes in steam at 100° | 57.3 | 57.1 |
| 20 minutes more in steam at 100° | 56.6 | 56.6 |
| 30 minutes more in steam at 100° | 55.7 | 55.9 |
| 1 hour more in steam at 100° | 55 7 | 55.6 |
| 2 hours more in steam at 100° | 55.7 | 55.6 |
| Rods remagnetized | 59.0 | 58.7 |
| 10 minutes in steam at 100° | 57.2 | 57.1 |
| 20 minutes more in steam at 100° | 56.6 | 56.4 |
| 30 minutes more in steam at 100° | 56.0 | 55.9 |
| 1 hour more in steam at 100° | 56.0 | 55.9 |
| 2 hours more in steam at 100° | 56.0 | 55.8 |

We also remagnetized the steel parallelopipedons Nos. I . . . VI, with hich the original experiments were made, and then annealed them in eam in the usual way, repeating the whole process a number of times. ıe following table contains the values of specific magnetism obtained:

TABLE 70.—*Specific magnetism, m, of saturated rods successively annealed at* 100°.

| Time of exposure to 100°. | I. | II. | III. | IV. | V. | VI. |
|---|---|---|---|---|---|---|
| Rods remagnetized | 17.82 | 13.96 | 20.14 | 16.22 | 27.20 | 22.58 |
| 1 hour in steam at 100° | 16.34 | 12.78 | 18.54 | 14.75 | 25.44 | 21.07 |
| 1 hour more in steam at 100° | 16.24 | 12.69 | 18.33 | 14.60 | 25.24 | 20.93 |
| 2 hours more in steam at 100° | 16.12 | 12.66 | 18.29 | 14.54 | 25.12 | 20.41 |
| Rods remagnetized | 17.84 | 13.94 | 20.12 | 16.03 | 27.40 | 22.80 |
| 1 hour in steam at 100° | 16.28 | 12.69 | 18.47 | 14.73 | 25.42 | 20.93 |
| 1 hour more in steam at 100° | 16.24 | 12.66 | 18.37 | 14.69 | 25.34 | 20.97 |
| Rods remagnetized | 17.77 | 13.91 | 20.09 | 16.00 | 27.25 | 22.71 |
| 10 minutes in steam at 100° | 16.25 | 12.73 | 18.31 | 14.64 | 25.60 | 21.01 |
| 50 minutes more in steam at 100° | 16.10 | 12.59 | 18.24 | 14.54 | 25.34 | 20.93 |
| 1 hour more in steam at 100° | 16.07 | 12.54 | 16.26 | 14.54 | 25.31 | 20.86 |

If the present behavior of the magnets, where the steel has practi-lly reached its limiting mechanical state for 100°, is contrasted with ıe above, where temper varies simultaneously with magnetism, a much

smaller and thoroughly uniform loss of specific magnetism is everywhere apparent. In the case of No. 11 the original loss amounted to $\frac{62.6-43.8}{62.6}=30$ per cent. nearly; whereas at present the average loss is only $\frac{59.0-55.9}{59.0}=5.3$ per cent. Similarly, the average loss of specific magnetism of the rods I . . . VI was originally $\frac{20.76-9.42}{20.76}=55$ per cent. nearly. Now we have only an average loss of $\frac{19.62-17.93}{19.62}=8.6$ per cent. But owing to the fact that these magnets had been specially treated at the outstart—repeatedly heated from 15° to 60°—an immediate comparison between the last results and those for No. 11 is not to be made.

We have thus arrived at a partial corroboration of certain results obtained by Moser and Riess,[144] and subsequently also by Dufour.[145] Following Moser and Riess, we have for the successive losses of a hard needle:

| | Per cent. |
|---|---|
| After the first magnetization | 44.0 |
| After the second magnetization | 6.1 |
| After the third magnetization | 4.4 |

But with this last result our observations are at variance. As has been stated, our data have invariably shown that when the maximum of permanent hardness corresponding to any temperature has once been attained, then the magnetic effects of repeated application of the same annealing process are identical, the losses of specific magnetism experienced by saturated rods constant.

*The direct and indirect effect of temperature.*—We conclude, therefore, that if it be our object to perspicuously represent the law of the phenomena in question, it is essential to discriminate between two species of magnetic loss. If the magnet is in such a condition—for instance glass-hard—that the higher temperature ($T$) produces a mechanical effect, then this is invariably accompanied by a magnetic effect peculiar to itself, and as experiment has shown, of relatively very large intensity. The reasons for this behavior are obvious. The existence of magnetism is conditioned by a strain of a particular and characteristic kind. The same is true of hardness. It is very probable, therefore, that the partial disappearance of one of these strains from any cause whatsoever will materially interfere with the intensity of the other.[146] Why the influence of the time of exposure to 100° is marked when the state of hardness is such that annealing produces both a mechanical and a mag-

[144] Moser u. Riess: Pogg. Ann., XVII, p. 403, 1829.

[145] Dufour: Fortschr. der Physik, 1857, p. 438.

[146] Whether mere magnetization produces a change in the temper of glass-hard steel is still to be investigated. In consequence of the very small variation of dimensions the anticipative effect must, of course, necessarily be small.

magnetic effect, is readily seen. For the latter effect must continue to vary until the limit of variation of the former has been fully reached; and the annealing effect of 100° in case of glass-hard steel is a diminution of hardness occurring at a very gradually decreasing small rate through infinite time.

When this has occurred—*i. e.*, when the final state of hardness due to an exposure to $T$ has been reached—we have to do with a purely magnetic phenomenon only. A rod magnetized to saturation and annealed at $T$° experiences a direct effect—a loss of specific magnetism which is relatively small, nearly independent of the time during which $T$ acts, and the cause of which may be loosely ascribed to a smaller coercive force at $T$ and to the effect produced by the thermal expansion on the magnetic strain. We may add that while in the first case, where the rod itself undergoes a change of state, a limiting value of specific magnetism was not fully reached even after 22 hours of annealing; in the second, the action is certainly complete after the lapse of an hour, and occurs in such a way that the principal part of the magnetism is lost within the first ten minutes.

The reasons fully appear why Moser and Riess found that when soft and annealed rods were used the losses were not only small, but occurred with the characteristic rapidity of those here enunciated. In this case an annealing effect due to 100° is manifestly impossible, and the peculiarities of the purely magnetic phenomenon are alone observed. It would moreover appear that the latter for a given temperature, $T$, is independent of the material used, of an intrinsically magnetic nature. At least Moser and Riess found for this loss

| | Per cent. |
|---|---|
| When the needle was soft | 13.6 |
| When tempered blue | 13.4 |
| When tempered cherry red | 13.7 |

We will waive this matter here, as it is our object to investigate it specially, paying particular attention, moreover, to the effect incident upon a variation of the dimensions L / D. Such an effect is already, though somewhat obscurely, apparent.

*Pre-existing magnetization.*—If the inference derived in the foregoing paragraph be correct, then must it be immaterial whether a glass-hard unmagnetic steel rod is first annealed, say in steam, at 100°, until the final mechanical state for this temperature has been practically reached and then magnetized to saturation, or whether the rod, *originally* saturated, is annealed and then remagnetized, as in the previous case. The ultimate result must, in other words, be independent of pre-existing conditions so long as these are effects of a lower order than correspond to the given temperature.

In order to give this question, which partakes of the nature of a crucial test, due experimental consideration, two rods, Nos. 13 and 14, of equal length, were broken from a glass-hard sample of the same

thickness (0.084 cm.) and material as Nos. 11 and 12. The constants of the new magnets are:

| | No. 13. | No. 14. |
|---|---|---|
| Length ..... | 9.1 | 9.1 *cm.* |
| Mass ..... | 0.379 | 0.381 *g.* |

Of these, No. 14 was magnetized to saturation; No. 13, however, left unmagnetized. Both were then exposed to the action of steam, and the progress of the annealing investigated by repeated measurements of the specific resistances of the rods. Unfortunately, a piece of No. 13 was accidentally broken off in clamping. The new rod (No. 13) was 8.7 cm. long and weighed 0.363 *g*. The two wires in their present condition would not, however, permit us to discuss the question from a sufficiently broad standpoint, and we, therefore, selected three other wires of the diameter 0.2 cm., so chosen as to present nearly the same specific resistances, viz:

| | |
|---|---|
| No. V..... | $s = 42.4$ $\left(\frac{cm}{cm^3}\ 0^\circ\ \text{microhm.}\right)$ |
| No. VI..... | $s = 42.6$ Do. |
| No. VII..... | $s = 42.2$ Do. |

The rods were tempered by sudden cooling after heating to redness in the flame of a blast-lamp. Out of the first but a single magnet was taken, No. 15, and but one, No. 16, from the second; while to the third and most homogeneous of the three the two shorter magnets, Nos. 17, and 18, owe their origin. It was intended to have the lengths of Nos. 15 and 16 and of Nos. 17 and 18 identical, but it is difficult in the case of wires of this thickness to break them off at a prescribed mark. Small variations of length are, therefore, unavoidable. The constants of the four magnets (0.21 cm. thick) are:

| | No. 15. | No. 16. | No. 17. | No. 18. |
|---|---|---|---|---|
| Length *cm.* | 7.2 | 7.3 | 2.90 | 2.95 |
| Mass ..... *g.* | 1.90 | 1.92 | 0.773 | 0.776 |

These were now treated in a manner analogous to that applied to Nos. 13 and 14; 11 hours of annealing in steam at 100° transferred them into the final state of temper for this temperature, not completely, it is true, but sufficiently so for the purposes. All were now remagnetized. Nos. 15, 16, 17, 18, acted on by steam for some time, and their magnetic behavior examined, were then remagnetized again, and once more annealed. Nos. 13 and 14, however, were first exposed to a lower temperature, that of boiling methyl alcohol at 66°, during a certain interval; and not until the magnetic limit for 66° had been fully reached

were they exposed in steam, in order that the limiting value of permanent specific magnetism corresponding to the new temperature (100°) might in its turn appear. The data expressing the magnetic effect of these operations are detailed in the following tables, 71 and 72. As before, $W$ denotes the resistance per meter of length of rod at $t°$, $s$ the corresponding specific resistances at zero.

TABLE 71.—*Limits of magnetic state at* 100°.

| Time of exposure. | Magnet No. 13. | | | | Magnet No 14. | | | |
|---|---|---|---|---|---|---|---|---|
| | $W$ | $t$ | $s$ | $m$ | $W$ | $t$ | $s$ | $m$ |
| *Glass-hard.* | ohm. | C. | microhm. | abs. E. | ohm. | C. | microhm. | abs. E. |
| 0m in 100° | 0.734 | 9.0 | 39.7 | | 0.741 | 9.1 | 40.1 | 51.4 |
| 10m in 100° | 721 | 9.0 | 39.0 | | 726 | 9.1 | 39.3 | 48.7 |
| +20m in 100° | 701 | 9.0 | 37.9 | | 707 | 9.0 | 38.2 | 45.8 |
| +30m in 100° | 683 | 8.0 | 37.0 | | 688 | 8.1 | 37.2 | 43.4 |
| + 1h in 100° | 666 | 9.0 | 35.9 | | 669 | 9.0 | 36.1 | 40.9 |
| + 2h in 100° | 646 | 9.0 | 34.9 | | 650 | 9.0 | 35.0 | 39.1 |
| + 3h in 100° | 632 | 9.0 | 34.1 | | 634 | 9.0 | 34.2 | 38. |
| + 4h in 100° | 622 | 9.3 | 33.5 | | 626 | 9.8 | 33.6 | 37.( |
| Rod remagnetised | | | | 49.9 | | | | 49.( |
| 1h in 66° | | | | 48.3 | | | | 48.( |
| + 2h in 66° | | | | 48.0 | | | | 47.8 |
| + 3h in 66° | | | | 48.0 | | | | 47.4 |
| 1h in 100° | | | | 47.5 | | | | 47.1 |
| + 3h in 100° | | | | 47.5 | | | | 47.1 |

TABLE 72.—*Limits of magnetic state at* 100°.

| Time of exposure. | Magnet No. 15. | | | | Magnet No. 16. | | | | No. 17. | No. 18. |
|---|---|---|---|---|---|---|---|---|---|---|
| | $W$ | $t$ | $s$ | $m$ | $W$ | $t$ | $s$ | $m$ | $m$ | $m$ |
| *Glass-hard.* | | | | | | | | | | |
| 0m in 100° | | | | | | | | 48.1 | | 32.3 |
| One day after tempering | 0.1277 | 8.7 | 42.4 | | 0.1282 | 8.8 | 42.5 | 47.2 | | 31.5 |
| 10m in 100° | 1219 | 9.3 | 40.4 | | 1218 | 9.3 | 40.3 | 37.4 | | 21.4 |
| +20m in 100° | 1165 | 9.6 | 38.6 | | 1167 | 9.8 | 38.6 | 33.2 | | 17.5 |
| +30m in 100° | 1128 | 9.7 | 37.3 | | 1129 | 9.7 | 37.3 | 30.3 | | 15.2 |
| + 1h in 100° | 1087 | 9.0 | 35.9 | | 1084 | 9.0 | 35.9 | 27.8 | | 13.4 |
| + 2h in 100° | 1048 | 9.1 | 34.6 | | 1049 | 9.1 | 34.7 | 26.0 | | 11.6 |
| + 3h in 100° | 1021 | 9.3 | 33.7 | | 1024 | 9.5 | 33.0 | 24.8 | | 11.2 |
| + 4h in 100° | 1011 | 10.0 | 33.3 | | 1008 | 10.00 | 33.2 | 24.5 | | 10.7 |
| Rod remagnetized | | | | 43.6 | | | | 45.3 | 29.2 | 30.1 |
| 10m in 100° | | | | 41.8 | | | | 43.7 | 27.8 | 28.6 |
| +20m in 100° | | | | 41.7 | | | | 43.6 | 27.6 | 28.2 |
| +30m in 100° | | | | 41.6 | | | | 43.6 | 27.4 | 28.2 |
| Rod remagnetized | | | | 43.4 | | | | 45.2 | 29.3 | 30.6 |
| 10m in 100° | | | | 42.1 | | | | 44.0 | 27.8 | 28.8 |
| +20m in 100° | | | | 41.9 | | | | 43.7 | 27.6 | 28.4 |
| +30m in 100° | | | | 41.7 | | | | 43.5 | 27.4 | 28.4 |
| + 3h in 100° | | | | 41.6 | | | | 43.4 | 27.3 | 28.2 |

*Magnetic effect of annealing—Final result.*—In this series of results our views are fully corroborated. When the limiting state of hardness conditioned by the temperature of annealing $T$ has once been reached, then it is wholly immaterial, in so far as the subsequent magnetic behavior is concerned, whether the rod was originally a magnet or not. The consecutive values of $m$ for Nos. 15 and 16, as well as Nos. 17 and 18, after 11 hours of annealing and remagnetization have been applied, manifest a perfectly similar progress throughout. The same is true of Nos. 13 and 14, both while in vapor of methyl alcohol and while in

steam. It will be observed that the limiting magnetic state for 66° differs from that of 100°, although neither is able to effect any further change in the qualities of the material. Whence it follows, in complete analogy with the results formerly found in the case of simple annealing, that in the present case each given temperature, after having been applied to a glass-hard rod to produce and consummate the mechanical effect, and thereupon to the remagnetized rod for magnetic effect, has its particular and characteristic magnetic limit.

*Simultaneous variation of specific resistance and magnetism (low temperature).*—In Fig. 21 the diminution of specific resistance, together with the simultaneous variation of specific magnetism due to annealing at 100°, has been graphically represented. The results are those above given for the magnets Nos. 11, 14, 16, 18. The similarity in the two sets of curves suggests an inquiry into the mutual dependence of these quantities. In figure 22 we have plotted specific resistance as abscissa

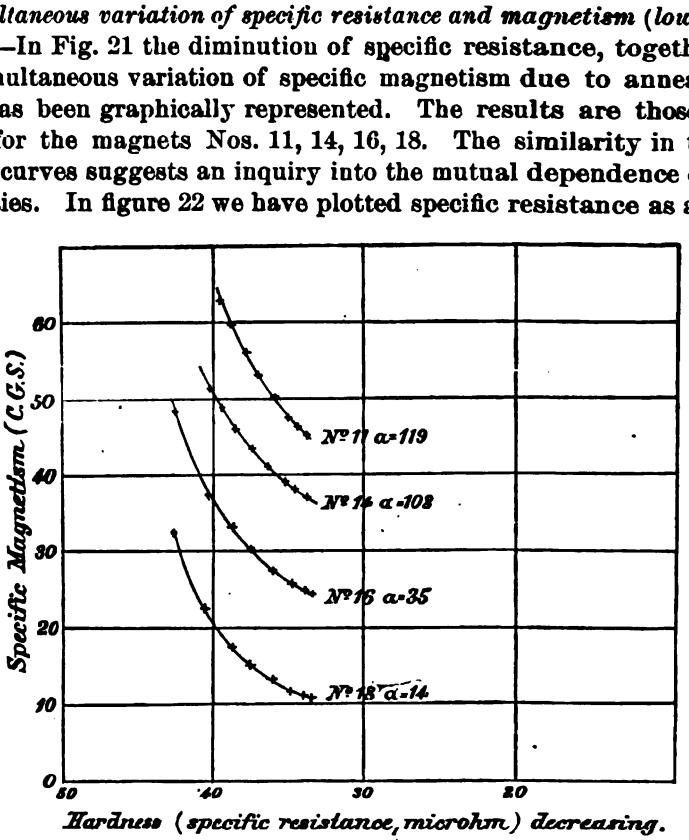



FIG. 22.—Simultaneous variation of specific magnetism and specific resistance in case of continued annealing (low temperatures).

and specific magnetism as ordinate. The points are found to lie on loci of small curvature, approximately parallel to one another. The members of the family appear the more nearly linear the greater $\alpha = \frac{L}{D}$ and therefore the simpler the linear distribution of the magnetism. All are, of course, only the initial parts of far more extensive curves to be obtained by continuing the annealing at temperatures higher than 100°.

The data for Nos. 11, 14, 16, and 17, moreover, show in how far the diminution of specific magnetism from the original to the final value, as

resulting from annealing, is dependent on the ratio of dimensions $\alpha$. We have the following values for the amounts lost:

No. 11 ..... $\frac{62.6-43.8}{62.6}=30$ per cent.; $\frac{L}{D}=\alpha=\frac{10}{0.084}=119$;

No. 14 ..... $\frac{51.4-37.0}{51.4}=28$ per cent.; $\frac{L}{D}=\alpha=\frac{9.1}{0.084}=108$;

No. 16 ..... $\frac{48.1-24.5}{48.1}=49$ per cent.; $\frac{L}{D}=\alpha=\frac{7.3}{0.207}=35$;

No. 18 ..... $\frac{32.3-10.7}{32.3}=67$ per cent.; $\frac{L}{D}=\alpha=\frac{2.95}{0.207}=14$.

It appears, therefore, that long, thin magnets lose decidedly less than those of small length. But the initial intensity is not without influence. For instance, although both No. 11 and No. 14 were originally saturated, the former retained a larger quantity, whether in virtue of its state of hardness or from small differences of chemical composition does not appear; for the loss of No. 11 is greater, or else that of No. 14 smaller, than the other values would indicate.

In a similar manner the influence of hardness appears in a series of experiments made with ten small steel parallelopipedons of nearly the same dimensions. These magnets (designated by No. VII to No. XVI), 2.5 cm. long, 0.4 cm. broad, and 0.3 cm. thick, of the same material, were glass-hardened in the same way—in so far as this is possible in the ordinary method of tempering—and finally magnetized to saturation by the action of the same magnetic field (helix). The following tabular comparison of the results, however, shows variations of a kind such that few consistent inferences, with the exception of that emphasizing the effect of hardness, can be deduced from them. But from this very fact the importance of structural effects is again clearly indicated.

TABLE 73.—*Limits of magnetic state at* 100°.

| | VII. | VIII. | IX. | X. | XI. |
|---|---|---|---|---|---|
| Weight (g) | 2.53 | 2.45 | 2.48 | 2.47 | 2.52 |
| Specific magnetism: | | | | | |
| Glass-hard, saturated | 11.18 | 14.11 | 14.03 | 15.11 | 14.15 |
| $4^h$ in steam | 2.70 | 2.89 | 3.93 | 4.34 | 4.06 |
| Rods remagnetized | 10.05 | 12.26 | 12.31 | 13.25 | 12.79 |
| $2^h$ in steam | 7.91 | 11.06 | 10.93 | 12.09 | 11.44 |
| Loss in per cent. of original value ($m$): | | | | | |
| First loss | 76 | 80 | 72 | 71 | 71 |
| Second loss | 21 | 10 | 12 | 9 | 11 |

TABLE 74.—*Limits of magnetic state at* 100°.

| | XII. | XIII. | XIV. | XV. | XVI. |
|---|---|---|---|---|---|
| Weight (g) | 2.51 | 2.41 | 2.48 | 2.39 | 2.43 |
| Specific magnetism: | | | | | |
| Glass-hard, saturated | 12.47 | 14.05 | 14.64 | 16.56 | 15.76 |
| $4^h$ in steam | 4.09 | 3.08 | 4.53 | 5.55 | 4.55 |
| Rods remagnetized | 11.50 | 13.00 | 13.61 | 15.72 | 14.85 |
| $2^h$ in steam | 9.80 | 11.82 | 12.45 | 13.70 | 13.34 |
| Loss in per cent. of original value ($m$): | | | | | |
| First loss | 67 | 78 | 69 | 67 | 71 |
| Second loss | 15 | 9 | 9 | 13 | 10 |

*Specific resistance and specific magnetism—Higher temperatures of annealing.*—The following final experiments on the relation between magnetic moment per unit of mass and the respective specific resistance, in case where a diminution of both qualities is effected by annealing, give further insight into the nature of this functionality. Two magnets, Nos. 19 and 20, were broken from a glass-hard rod, No. VIII (diam. 0·147 cm.), and exposed for different lengths of time in hot baths. The constants of the magnets are these:

| | | |
|---|---|---|
| Length ..... | $L = 1.50$ | 9.09 cm. |
| Mass ..... | $\mu = 0.193$ | 1.172 *g* |
| Dimension ratio ..... | $\alpha = 10.2$ | 61.9 |

The results obtained by examination at different stages of the operation of annealing are given by the following table:

TABLE 75— *Simultaneous variations of magnetization and galvanic hardness, for continued annealing.*

*Magnets Nos. 19 and 20.*

| Time of exposure. | *W* 1 *m* | · *t* | *s* | $\frac{m}{m}$ No. 19 | $\frac{m}{m}$ No. 20 |
|---|---|---|---|---|---|
| | *Ohm* | °C. | *microhm.* | | |
| Glass-hard ..... | 0.283 | 11.5 | 47.9 | 21.25 | 39.1 |
| 20$^m$ in 100° ..... | 0.267 | 12.0 | 44.2 | 12.56 | 29.5 |
| + 2$^h$ in 100° ..... | 0.245 | 12.0 | 40.5 | 7.74 | 22.3 |
| +10$^m$ in 185° ..... | 0.202 | 11.6 | 33.4 | 3.98 | 18.8 |
| + 6$^h$ in 185° ..... | 0.162 | 11.3 | 26.7 | 2.45 | 17.5 |
| + 1$^m$ in 330° ..... | 0.120 | 10.0 | 19.6 | 0.25 | 14.4 |

These curves (figure 23) pass from convexity as regards the axis *x* through a point of circumflexion into concavity. Both loci are very

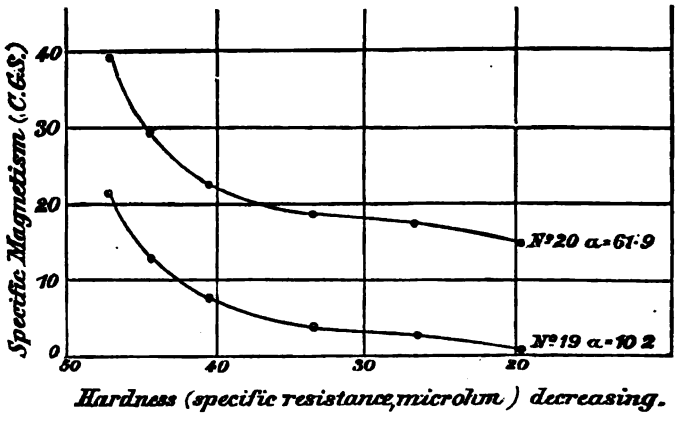



FIG. 23.—Simultaneous variation of specific magnetism and specific resistance in case of continued annealing (high temperatures).

much alike, decreasing rapidly near the origin as well as near their extreme points (annealed at 330°). Short magnets lose their magnetiza-

tion when exposed to temperatures at more rapid rates than long ones. The latter, on the whole, show greater magnetic permanence than the former.

The interpretation of these phenomena is difficult. But it is in place to present the salient points to be considered here. For the reasons given on page 145, a perspicuous relation between magnetism and resistance can only be anticipated in case of linear rods. The results in hand conform with this view to the extent that the observed curvature diminishes in marked degree in proportion as $\alpha$ increases (cf. Fig. 22). In general, moreover, there are two phenomena superimposed: the direct magnetic effect of temperature and a much larger indirect effect, the latter being the magnetic effect of a change of hardness (annealing) produced by temperature, simultaneously. In the case of a given rod ($\alpha$ constant and large) the direct effect is a function of time and temperature. The indirect effect, on the other hand, must be expressible as a function of $s$ since this quantity shows the amount of change of mechanical state. Take rod No. 11, in which $\alpha$ is large, for instance, and deduct the direct effect given in Table 69 from the superimposed effects given in Table 68; the variation of magnetic moment ($m'$) and hardness for the indirect effect alone is given in this table:

| Time of annealing. | Direct effect. | Indirect effect. | $s$ |
|---|---|---|---|
| | $m=$ | $m'=$ | |
| 0 | 62.6 | 62.6 | 39.5 |
| 10 minutes | 59.5 | 61.8 | 38.7 |
| 20 minutes | 56.0 | 58.4 | 37.6 |
| 30 minutes | 52.6 | 55.6 | 36.7 |
| 1 hour | 50.0 | 53.0 | 35.7 |
| 2 hours | 47.3 | 50.3 | 34.8 |
| 3 hours | 46.1 | 49.1 | 34.1 |
| 4 hours | 45.1 | 48.1 | 33.5 |
| 5 hours | 44.3 | 47.3 | 33.1 |
| 6 hours | 43.8 | 46.8 | 32.8 |

Here, therefore, the relation between $m'$ and $s$ is approximately linear. Thus far, however, magnetizability has decreased; its variation is small.

A passage to higher annealing temperatures is accompanied by a marked *increase* of magnetizability. The actual magnetism possessed by the rod after thorough annealing in the lower temperature (100°), may, therefore, fall so far short of the attainable saturation at a higher temperature as not to be affected sensibly, either by the direct or the indirect influence of the said higher temperature. This inference is substantiated by the data in Table 75 for the rods Nos. 19 and 20. The slight variation of specific magnetism in the case of higher annealing temperatures (185°, 330°) is exhibited in Fig. 23 by the approximately horizontal parts of the corresponding curves. It follows, therefore, that before the relation of magnetism and resistance can be thoroughly discussed, the character of the relation between maximum of permanent magnetism and hardness, which in Figs. 17 and 18 is

graphically given for ordinary temperatures, must be known for all other temperatures. In other words, a family of curves such as given by Figs. 17 to 20 exists with equal definiteness for higher temperatures (100°, 200°, 300°, etc.) and from the co-ordination of such series of families the value of the direct or purely magnetic effect of temperature is deducible for any given circumstances.

Furthermore, the increments of the superimposed magnetic effects and the simultaneous increments of specific resistance should be compared when obtained under circumstances such that the (linear) rod remains, as nearly as possible, in a state of magnetic saturation. It is, therefore, essentially necessary to compare increments. The character of the direct effect being known, that of the indirect effect follows.

It will be observed that the difficulty encountered here is the result of variation of magnetizability. Moreover, the direct and indirect effects need not necessarily vary independently of each other when superimposed.

## MAGNETIC RETENTIVENESS AS REGARDS THE EFFECTS OF PERCUSSION AND TIME.

*Effects of temperature, percussion, time.*—The use of annealed in the place of glass-hard magnets for magnetic instruments, procures for us the decided advantages of a diminished sensitiveness as regards the influence of temperature. If a magnet, which is thus to be used, is annealed at a given higher temperature $T°$— we will continue to suppose it produced with steam, a method both convenient and satisfactory—until the limit of hardness characteristic of this temperature has been attained, then will this material be perfectly passive in so far as temperatures below $T°$ are concerned. If the rod is then magnetized to saturation—how often soever this may have been previously done is entirely without consequence—and again thoroughly annealed at $T°$, then the magnet will in a comparatively short interval of time arrive at a stable and limiting magnetic state, which when exposed to temperatures below $T°$ will in its turn be equally passive, *i. e.*, suffer no *permanent* magnetic variations. But where magnets are to be used for purposes of measurement, a full guarantee for their stability as regards permanent effects from changes of atmospheric temperature is not the only desideratum. The efficiency of the magnet is conditioned almost to an equal extent by its power of magnetic retention against such influences as percussion or rapid vibration, or indeed the prolonged effect of time. That the methods previously employed for the construction of magnets for practical purposes are invariably deficient in this respect is well known, and it will therefore be adequate to add in this place a single authoritative statement only.

*Observations of Wild.*—In the "Annalen des physikalischen Centralobservatoriums," St. Petersburg, p. 63, 1878, H. Wild discusses the efficiency of Edelmann's bifilar magnetometer and refers to the magnet of this apparatus as follows:

Obgleich der Magnet nach seiner Magnetisirung abwechselnd einer Temperatur von 0° und 30° ca. 30 Mal ausgesetzt worden war, um ihn permanenter zu machen, fand doch eine schnelle Abnahme des magnetischen Momentes statt, so dass sie mehrfache Verstellungen und Veränderungen erforderte. Damit nämlich die Scala noch nicht ganz aus dem Gesichtsfelde herausrücke, musste schon am 17. April (seit Anfang December) der Torsionswinkel um 1° 51′.5 vermindert werden, um wieder die Mitte der Scala in das Gesichtsfeld des Fernrohrs zu bringen . . . Da die Verminderung des Magnetischen Momentes des Stabes auch in folgenden Monaten ungeschwächt fortdauerte, so befürchtete ich, es sei der Magnet schlecht und liess nach dem Muster desselben einen neuen herstellen.

A numerical estimate of these variations is furnished by the following data: The magnet in question was 8.0 centimeters long, 2.1 centimeters broad, and 0.22 centimeter thick; its magnetic moment $M$ and specific magnetism $m$ were found initially, after the change of temperature mentioned, to be—

$$M=954.2 \qquad m=28.31;$$

after 9 months:

$$M=914.5 \qquad m=27.14$$

The mean loss per month was therefore as high as 0.46 per cent. of the original value, but the new magnet was hardly found to be preferable to the old. On page 8 of the "Annalen des Centralobservatoriums, etc.," 1879, H. Wild reports as follows:

Auch der neue Magnet verlor nach der Aufhängung am Bifilar noch fortwährend bis zum Schlusse des Jahres so viel Magnetismus, dass eine Bearbeitung der Beobachtung an diesem Bifilar nicht erfolgen konnte.

This magnet had also been subjected in the usual manner to 16 successive changes of temperature between 0° and 56°.

The following data show the extent of these variations accurately:

On the 29th of December, 1878, immediately after magnetization the magnetic moment $M$ and the specific magnetism $m$ of the bar were

$$M=1852 \qquad m=55.0$$

Some time after, on the 4th of February, 1879,

$$M=1756 \qquad m=52.1$$

After 16 changes of temperature between 0° and 55°,

$$M=1694 \qquad m=50.3$$

The explanation of these results on the basis of our investigation is no longer difficult. It was customary—following Riess and Moser, who considered the time of exposure to the higher temperature as of no consequence—to put the principal stress on the condition of a change of temperature. As a result, the magnet was subjected to the influence of the higher temperature only long enough to heat it uniformly throughout. Even Holmgren contended that permanent and hurtful effects of

temperatures between given limits (0° and 100°) could be made to vanish by repeated alternations of temperature from the inferior (0°) to the superior (100°) limit, and with this end in view heated and recooled his magnet fully 213 times. Possibly this might actually suffice. If, however, as is usual, only 20–40 alternations are made (and even this is tedious and troublesome, consuming much time), a sufficiently advanced state of annealing can hardly have been attained. To a much smaller extent even will this be the case where temperatures only as high as 50° are employed. The magnet therefore practically remains in an extreme of glass-hard state, a condition in which strains of an intensity so enormous exist in the rod, that irrespective of other causes, changes of mechanical state purely the results of time may be anticipated. By the process of annealing, these abnormal strains, so to speak, are diminished to values which insure far greater stability of mechanical state.

Better results are obtained by application of higher temperatures than 50°, if the action of these is sufficiently prolonged. For instance, a magnet, destined to become a part of the bifilar at the Physical Institute at Würzburg, was, after magnetization, held for ten minutes in boiling water and then adjusted in place. The original specific magnetism was found to be

$$m = 28.95 \qquad M = 2397$$

After the annealing

$$m = 24.43 \qquad M = 2023$$

Since that time the bifilar has been in continual use, and the behavior is quite satisfactory. If we observe how great is the initial change of hardness, relatively speaking, during the first ten minutes of exposure to 100°, we infer that even this amount of annealing is sufficient to reduce the hurtful excess of strain to a degree that insures fair stability. A constancy of magnetic moment under like conditions is the result.

Obviously, however, results of better permanence will be reached where the annealing at the practically convenient temperature of 100° is sufficiently prolonged to leave the magnet in the limiting mechanical state characteristic of this temperature. But unfortunately such a process would diminish the magnetic intensity very materially; indeed, in the usual case of a ratio of dimensions $\alpha = 10 \ldots 20$, a loss of even more than 70 per cent. is frequently met with in the above. If, however, the bar is again magnetized to saturation, the original intensity will be very nearly regained; whereupon, if the process of annealing is once more applied, a limiting magnetic state possessing the desired stability, is reached, with a loss of magnetization amounting to *only* 5 to 10 per cent.

*Maximum hardness and magnetization for* 100°, *stable at* 0°.—Now, there is ample reason for the belief that rods in this singular magnetic state possess the best available qualities of magnetic retention. If a glass-hard saturated magnet be dropped, the result is invariably a loss

of magnetic moment. This is by no means the case with rods subjected to the treatment specified. Even if a sharp blow be intentionally administered, or the magnet be thrown with violence upon the floor, the action is without apparent magnetic effect. As an example we will cite the following observations made with a short and thick magnet. It is known that the retentiveness of such is much inferior to that of long, thin rods.

The magnet was 2.5 centimeters long, 0.4 centimeter broad, and 0.3 centimeter thick. At the outset it was purposely boiled for but 4 hours in water; then magnetized to saturation, and subjected during 2 hours to the action of steam. Our magnetometer showed the following average deflection of five readings (scale-parts millimeters):

$$n = 27.00$$

Then the magnet was placed on a block of wood, and, with the aid of a second block, sharply struck 30 times at right angles to the direction of its magnetic axis, and 20 times in a direction with it. After placing the magnet aside for a time, in order that its original temperature might be reassumed, the reading at the magnetometer was

$$n = 26.97$$

The same process was repeated, with the result

$$n = 26.93$$

Even if the slight diminution from 27.00 to 26.93—about 0.3 per cent.—had existence in fact—that is, was not due to errors of observation, but to magnetic moment lost—still, as it represents the magnetic effect of 100 powerful blows, it is certainly negligible. But this magnet has not yet reached the maximum of permanent hardness for 100°. Whence it follows that, from a rigid application of our method, results more satisfactory even than this are to be looked for.

Experiments of a determinate and final character were made upon a hollow cylindrical magnet, weighing 109.32 *g*. The length of the tube was 16 centimeters, its outer radius 1.6 centimeters, its inner radius 1.2 centimeters. After tempering to glass-hardness it was magnetized to saturation, then annealed in steam at 100° for a period of 30 hours. After this the cylinder was once more magnetically saturated and thereupon reannealed in steam for 10 hours. The specific magnetism, determined from time to time, showed the following values:

| | |
|---|---|
| Magnet glass-hard, saturated | $m = 41.0$ |
| 10 hours in steam at 100° | $m = 26.1$ |
| 20 hours in steam at 100° | $m = 25.2$ |
| 30 hours in steam at 100° | $m = 24.8$ |
| Magnet annealed, resaturated | $m = 39.9$ |
| 5 hours in steam at 100° | $m = 33.8$ |
| 10 hours in steam at 100° | $m = 33.1$ |

In the last instance the needle of our magnetometer for a distance of 72.9 centimeters of the magnet and a rotation of the same of 180°, was deflected over $n=475.6$ scale-parts (millimeters), where 250 centimeters intervened between mirror and scale and the whole measurement was subject to the conditions of Gauss's second position.

The magnet was now introduced into a long and wide glass tube and allowed to fall vertically for a distance of 1.5 meters, impinging on a block of wood. This was done once with the north pole and again with the south pole downward, whereupon the deflection was found to be $n=475.2$ scale-parts, and 10 minutes later $n=475.6$ scale-parts.

We then allowed the same magnet to fall in horizontal position from a height of $\frac{1}{2}$ meter upon the floor. After ten of these descents the magnetometer showed $n = 474.7$ scale-parts, and five minutes later $n=475.0$ scale-parts.

Finally the magnet was again introduced into the glass tube and dropped in vertical position from a height of 1.5 meters, with the north and south poles alternately foremost. After ten repetitions of this treatment we observed the deflection $n = 473.3$; after three minutes, $n=474.0$; after thirty minutes, $n=475.5$.

The observed difference may therefore safely be referred to temporary thermal variations, partly incident to the percussion experienced by the rod, partly due to contact of the latter with the hand of the operator. A destructive effect due to percussion cannot be said to be apparent at all, despite the intense shocks to which the magnet was exposed. The temperature of the room (=6°.0) did not vary during experiment.

After these results, the inference is warranted that the magnetic retentiveness of rods tempered and saturated in the manner set forth will be proof against effects of cold of the same order, such for instance as are met with by observers in the polar regions. Direct researches on this point are contemplated. Whether or not cold is capable of producing a *mechanical* annealing effect is unknown. Certain it is that it would be discernible only by such sensitive methods as are employed in Chapter II. But the marked magnetic effect produced by reduction of temperature has long been understood. Indeed, J. Trowbridge, by the use of carbonic acid and ether, was able to diminish the magnetic moment in this way fully 66 per cent. In the case, however, where a rod is in the magnetically stable condition as regards an elevation of temperature of say 100°, it is altogether probable that if cooled to a similar extent it will continue to possess the desirable quality in question.

We believe, therefore, in the method described, actually to have found a process for the construction of magnets of exceptional constancy and of powerful magnetic retentiveness. In how far this quality may be preserved in the lapse of time, will have to be deferred to the verdict of observers by whom such magnets may possibly be used. How much more reliable and satisfactory measurements made in different parts of the earth will be, when the magnets are no longer liable to injury from

the shocks and blows unavoidably encountered during transportation, needs no further comment.

In conclusion, we desire to add the following rules for the practical construction of magnets:

1. Rods tempered glass-hard are never to be used as essential parts of magnetic instruments.

2. After having tempered the rod in a way that insures a uniformity of glass-hardness throughout its length, expose it for a long time (say 20 to 30 hours; in the case of massive magnets even longer intervals are preferable) to the action of steam at 100°. The operation may be interrupted as often as desirable. The magnet has now reached the highest or hardest of the mechanical states which are no longer influenced by temperatures below 100°.

3. Magnetize the rod, no matter whether originally a magnet or not, to saturation, and then subject it during a period of about 5 hours (in the case of large massive magnets even longer intervals are preferable) to the action of steam at 100°. Then the magnet will have reached the highest and most powerful of the magnetic states which are no longer influenced by temperatures equal to or less than 100°. The magnet is now ready for use.

It may be added that the advantages of using steam are two-fold: In the first place, the process is exceedingly convenient and economical.[144] In the second, it will be remembered that the temperature 100° ultimately leaves the rod in a condition in which the change of capacity for magnetization, as hardness decreases, takes place along the contours of a very flat minimum.[145] Even if slight changes of hardness should subsequently occur, their magnetic effect would be reduced to insignificance, in virtue of the singular variation just mentioned.

## ADDENDUM.

### RESULTS OF PROF. H. WILD, OF ST. PETERSBURG, WITH REFERENCE TO MAGNETS TEMPERED AND MAGNETIZED BY THE METHOD PROPOSED IN THIS CHAPTER.[146]

We are fortunate in being able to cite in this place some results confirmatory of the efficiency of the method for the treatment of magnets proposed in this chapter bearing the authority of Professor Wild. In his work on the absolute value of Siemens' mercury unit, Professor Wild

[144] A flask with a long neck will be found serviceable. The steam condensing in the latter runs back into the bulk of boiling water. Or the suspended magnet may simply be boiled. The prolonged action of steam is in no way deleterious or corrosive. The rods are etched uniformly black and may thus be polished.

[145] Cf. Chapter V, p. 141.

[146] H. Wild: Mémoires de l'Académie impériale des sciences de St.-Pétersb., VII^e sér., T. XXXII, No. 2, p. 36.

made use of a large magnet constructed with exceptional care by H. Freiberg, out of "Eibiswalder naturhartem Wolfram-Stahl." Its dimensions (rectangular parallelopipedon) and weight are these: length, 29 centimeters; breadth, 3.6 centimeters; thickness, 1.2 centimeters; weight, 1,030 grams. This magnet was carefully tempered by heating to low redness and sudden cooling in lime-water at 20°. After being magnetized to saturation between the poles of a powerful electro-magnet, it was kept at 100° for 35 hours; thereupon again magnetized and exposed to steam for 10 hours more. The following are the observed magnetic moments (C. G. S.) at 20°:

| 1883. | | |
|---|---|---|
| April 27 | After the first magnetization ..... | $32.60\times10^3$ |
| April 30 | After 35 hours' exposure to 100°..... | $24.56\times10^3$ |
| April 30 | After the second magnetization..... | $31.48\times10^3$ |
| May 1 | After 10 hours' further exposure to 100° | $29.15\times10^3$ |

On June 21, 1883, at 20°, Wild obtained for the same quantity, $28.8\times10^3$. The magnet, despite the treatment which it had experienced, therefore, still lost about 1 per cent. of its total moment, during the intervening three months. But this variation is little more than 0.0001 of the total intensity per day, if the loss were proportional to time. Referred to July 1, however, when the actual measurements were commenced, the said decrement cannot be estimated as above 0.00005 per day—particularly so if it be borne in mind that the diminution in question must gradually vanish at a continually decreasing rate through infinite time, or that a final and definite moment is being asymptotically approached. Indeed, the said limit was practically reached in the second third of July, as the following results show. Wild further remarks that final magnetization of 28 C.G.S. units of magnetism per gramme is to be considered as a satisfactory value. The results in question are as follows:

| Date. | $M:10^3=$ | Differs from the mean by |
|---|---|---|
| July 21 | 28.8018 | |
| July 22 | 28.7846 | +0.00043 |
| July 26 | 28.7749 | — 54 |
| Aug. 3 | 28.7760 | — 43 |
| Aug. 4 | 28.7771 | — 32 |
| Aug. 5 | 28.7834 | + 31 |
| Aug. 10 | 28.7844 | + 41 |
| Aug. 11 | 28.7754 | — 49 |
| Aug. 13 | 28.7870 | + 67 |
| | Mean $M:10^3=28.7803$ | ±0.00045 |

The value for July 21 is not included in this mean.

We venture to remark that with so unusually large a magnet even better results could have been obtained by repeated boiling and remagnetization. In consideration of the dimensions, the decrement of 1 per cent. is by no means surprising. The tubular magnet discussed in the above was operated upon three successive times by our method, before definite adjustment for absolute work. We are not aware, however, whether it will not take some time, in order that a magnet kept at 100° may thoroughly regain the state of molecular equilibrium for 20°.

# CHAPTER VII.

## A PHYSICAL DEFINITION OF STEEL BASED ON THE ELECTRIC BEHAVIOR OF IRON WITH GRADUALLY INCREASING DEGREES OF CARBURATION.

### INTRODUCTION.

*Nature of the problem.*—A detailed and thoroughly exhaustive study of the problem in hand, viz, in how far the effect of carburation on the galvanic and thermo-electric properties of iron is available for the general classification of iron-carburets, calls for working facilities at a puddling furnace, for instance, or other technically satisfactory agency for the decarburation or carburation of iron. Possibly, however, similar work might be done on a small scale in the laboratory, if the necessarily complicated apparatus or opportunities for constructing the same were at the observer's disposal. These advantages were not within our reach.

The problem is of a kind, moreover, which is apt to mislead the investigator into insuperable and almost infinite complications. To avoid these it is absolutely necessary to conduct the experiments with reference to some thoroughly preorganized plan. In the absence of the above-mentioned metallurgical apparatus we were obliged to content ourselves with commercial products, and the main purpose of the present memoir has therefore been restricted to the development of a plan or scheme of operations for the general and tentative study of the electrical behavior of iron-carburets. These efforts have not been unsuccessful; indeed they appear to be of considerable promise. They have already afforded us a method for the physically exact definition of steel which we regard as important. As a whole, the present chapter furnishes an essential and interpretative sequel to our researches on the hardness of steel.

*Electrical manifestation of mechanical properties.*—The very remarkable effect of rapid and of prolonged cooling from red heat, respectively, on the physical and chemical properties of iron-carburets has always been a subject of great metallurgical interest.[147] In the case of steel the contrast between the two states or conditions thus produced is particularly well marked and of the greatest practical value. Experience has shown, however, that the said processes may be applied, with much advantage, to most of the other iron-carbon products. It is thus that

[147] On Karsten's theory, relative to the nature of these effects, see Percy's Metallurgy, edited by Wedding and others, Vol. II, p. 167, *et seq.*, Braunschweig, 1864.

the question naturally suggested itself to us, whether the remarkable parallelism discovered in the variation of the degree of hardness of steel and its galvanic and thermo-electric properties was not to be considered as only a special case of the behavior of iron-carburets generally, under analogous circumstances. In this respect we believed ourselves justified in predicting that those characteristic mechanical qualities which distinguish steel from other iron-carburets must necessarily be sharply outlined in a general electrical diagram adapted to the classification of iron-carburets as a whole. A similar idea, as we subsequently found, seems incidentally to have occurred to Joule,[148] since he remarks, after having given the necessary experimental data: "I believe the excellence of the latter metal (steel) might be tested by ascertaining the amount of change in thermo-electric condition which can be produced by the process of hardening." But neither Joule nor others have given the subject more than this inadequate consideration, and it was not until our investigations on steel had been fully developed that the problem attracted our attention.

*Critical operations.*—At first sight a comparison of the electrical intervals comprehended between the hard tempered, and soft annealed states, appeared to be rich in promise; but the processes of slow and of most rapid cooling possible, from red heat, are as yet not sufficiently defined, even if we abstract from decarburation, etc., for obtaining iron carburets in two characteristic physical states. In the case of slow cooling the temperature in red heat to which the specimen has been exposed, as well as the time during which exposure takes place are important items, particularly when the cast-irons are under examination. In the case of rapid cooling the temperature to which the red-hot rod is suddenly and permanently lowered is additionally to be considered. It would not, however, be difficult to define the two processes in question succinctly. A rod, for instance, suddenly chilled from red heat in water at ordinary temperature and then annealed by long exposure in ether vapor at 35° might appropriately be termed glass-hard; if annealed in vapor of sulphur (500°) or of cadmium (700°), soft. For the very large and physically important class of iron-carburets, wrought-iron, low-carbureted steel, and steel, these details, fortunately, do not produce any serious distortions; the thermo-electric hardness and the specific resistance of steel, no matter what the process may have been by which a given rod was softened, remain very nearly constant in value—at least when compared with the enormous range of variation of these qualities due to tempering. The same is true for the hard condition of the carburets between iron and steel, where it is only necessary to choose the temperature before sudden cooling sufficiently high to insure the appearance of hardness, and to chill in water at ordinary

[148] Joule: Phil. Trans. 1859, I, p. 96.

room-temperature. Decarburation is, however, under all circumstances to be avoided,[149] and the exposures to high temperature must not be prolonged. It follows therefore that it will be expedient to commence the present investigation by a consideration of the electrical properties of the carburets in question, that is such in which the total carbon is less than about 2 per cent. To this may be added that within the interval (0—2 per cent.) those modifications in the mode of occurrence of the carbon in iron, which are the cause of such great diversity in the character of the different species of cast iron, are as yet comparatively without marked influence. Thus it appears that our results for this set of products may be considered as satisfactory and definite. In order to complete the discussion conveniently, however, it is desirable to include certain essential properties of the cast-irons, or in other words to prolong the loci of our diagrams into the region of cast-iron, without going into any details. That this is readily possible will appear in the sequel.

A further introductory remark may be added here. Commercial iron-carburets are never pure, but contain in greater or smaller amounts vitiating impurities like phosphorus, sulphur, silicon, and the like. Each of these produces its own electrical effect, as has been seen in the earlier chapter (III) on alloys. The discrepancy thus introduced need not by any means be negligible, and full consideration is given to it in a later paragraph. For the present it will be expedient to suppose this secondary electrical effect to be absent, or that the material in hand is a pure iron-carbon product.

*Nomenclature.*—As a convenient nomenclature to be used throughout, we will designate the process of *softening* steel, that is cooling from red heat as slowly as necessary by the Roman numeral "*I*"; the process of sudden cooling from the same temperature (*hardening*, tempering, glass-hard) by the Roman numeral "*II*." In like manner all constants which refer to *I* or *II*, are to be marked with the subscript 1 or 2, respectively. For instance, $h_1, s_1 \ldots h_2, s_2 \ldots$ In like manner we may, without confusion, consider "soft state" and "glass-hard state," "state *I*" and "state *II*," respectively identical, etc.

[149] In this place it is well to call to mind an important result of Forquignon's (Ann. de Chim et de Phys. (5) XXIII, p. 538, 1881). He found that steel kept at red heat for seventy-two hours, in an envelope of hematite, lost nearly one-half of its total carbon. This corresponds to the loss of nearly four-fifths of total carbon, due to continued exposure of cast iron to red heat in the preparation of malleable cast iron (Percy op. cit., p. 143.) In many physical experiments with steel, particularly in magnetic work, it is often necessary to soften steel by heating it to redness for some time. It is therefore obvious that the product thus obtained cannot be considered identical, as regards total carburation, with the original carburet. Possibly this method of eliminating carbon may be available for obtaining points in an electric diagram corresponding to iron-carburets lying between iron and steel.

## WROUGHT-IRON.

*Electrical data.*—Pure iron subjected to the process *II* is mechanically indistinguishable from the same metal when subjected to *I*. So also the electrical difference between these two states is practically insignificant. This is true approximately for commercial iron with less than 0.2 per cent. of carbon, and the more nearly true, moreover, the smaller the amount of this element.

For the electrical conductivity of iron Chwolson[150] gives the following results: If a hard-drawn wire is ignited at low redness its electrical resistance is found to vary about −0.4 per cent. If the ignition be intense about +5.3 per cent. The process *II* produces a variation of only 0.7 per cent. in comparison with the hard-drawn state. If, therefore, we compare the rod in the state *II* with the same rod in the state *I*, we find a total electrical change about +1.1 per cent. or −4.6 per cent., respectively, according as *I* was produced by gentle or by intense ignition.

For results of this kind, with reference to the thermo-electric behavior of iron, we searched in vain. But the relation between the variations of thermo-electric and galvanic constants is initially (*i. e.* for very small amounts of a foreign element alloyed to any given metal) linear, as we proved both in the case of steel and of alloys of silver. Hence results of the same order as Chwolson's may be at once predicted for the thermo-electric behavior of commercial iron. Sir William Thomson[151] found that the thermo-electric hardness[152] of iron, like that of steel, is increased by the process *II*. Joule[153] finally remarks, "I find that in steel the (thermo-electric) change is in the same direction as in iron, but of enormously greater magnitude."

These small variations amounting to less than 2 per cent. of the total resistance or thermo-electric hardness, are for the present purposes at least, quite negligible; particularly so when contrasted with the corresponding change of the electrical constants of steel (200–300 per cent.). Where great accuracy is sought for, special measurements may be made. For this reason we accept for wrought iron the values for the electrical constants given in the following table (76). Here thermo-electric hardness is represented by $h$, specific resistance by $s$; $h_1$ refers to iron subjected to process *I*; $h_2$ to the same wire subjected to process *II*, etc., as has been stated. Furthermore $\Delta h = h_2 - h_1$; $\Delta s = s_2 - s_1$; $\Delta \log$

[150] Chwolson: Bulet. de St. Petersb., X, p. 379, 1877; also Carl's Rep., XIV, p. 26, 1878.

[151] Thomson: Phil. Trans., 1856, III, p. 722.

[152] On the definition of thermo-electric hardness, see our paper in Wied. Ann., XI, p. 970, 1880, or this memoir, Chapter II, p. 65.

[153] Joule: Phil. Trans., 1859, I, p. 95–97.

$h=log\ h_2-log\ h_1$; $\Delta log\ s=log\ s_2-log\ s_1$. The object of these differences will appear below. For $h$ and $s$ the values obtained elsewhere[154] are given. Microvolts, microhms, and square centimeters are the fundamental units: *log* refers to Brigg's logarithms.

TABLE 76.—*Electrical constants of wrought-iron.*

| Material. | Thermo-electric hardness. | | Specific resistance. | | $\Delta h$ | $\Delta s$ | $\Delta \log h$ | $\Delta \log s$ |
|---|---|---|---|---|---|---|---|---|
| | $h_1$ | $h_2$ | $s_1 \frac{cm}{cm^3}0°$ | $s_2 \frac{cm}{cm^3}0°$ | | | | |
| Wrought iron..... | *Microvolt.* 4.7 | *Microvolt.* 4.7 | *Microhm.* 12.2 | *Microhm.* 12.2 | Zero. | Zero. | Zero. | Zero. |

## STEEL.

*Electrical data.*—If we suppose the degree of carburation of iron to increase continuously from zero to about 1.5 per cent., the difference in mechanical hardness between states *I* and *II* will likewise increase continuously until steel is reached. For the purpose of defining the relatively enormous interval peculiar to the latter substance technically, metallurgists are in the habit of using some empirical criterion—for instance, the power to give sparks with flint.[155] It is, moreover, of the greatest practical importance that this phenomenal change of mechanical condition is confined to state *II*, and that state *I*, as regards hardness at least, is not readily distinguishable from wrought iron.

A large number of results on the electrical behavior of steel were discussed above. It will therefore only be necessary, in this place, to recall to mind the electrical interval *II–I* for this substance in a table constructed on the plan of the preceding, and therefore needing little further elucidation. For state *II* the largest values[156] occur in case of rod No. 28.

$$h=17.7 \text{ and } s=41.5$$

But later experiments[157] furnished considerably harder wires, the results

[154] Chapter II, p. 61. The mean values for the three iron wires there examined are here given.

[155] Cf. Karsten: Karsten's und v. Dechen's Archiv, XXV, p. 223 et seq., 1853; also Jeans, "Steel, its history," etc., London, Spon, 1880, pp. 533–542.

[156] Cf. Chapter II.

[157] See our paper, Wied. Ann., XX, p. 640, 1883.

for which are not given in the digest in question. The hardest of these showed $s=47.5$. If we put $h=ns$, there follows,

$$h=19.6 \text{ and } s=47.5$$

The minimal values for state *II* are those of rod No. 39:

$$h=15.1 \text{ and } s=34.9$$

The largest values for state *I* are given by No. 46:

$$h=6.9 \text{ and } s=16.0$$

and the smallest by No. 47:

$$h=5.0 \text{ and } s=14.0$$

The following table (77) contains both extreme and mean values for the different constants, the largest being put on the horizontal row *l*, the smallest on the row *s*, the mean on the row *m*. All of these are obtained from a combination of the data just cited.

TABLE 77.—*Electrical constants of steel.*

| | Thermo-electric hardness. | | Specific resistance. | | $\Delta h$ | $\Delta s$ | $10^6 \times \Delta \log h$ | $10^6 \times \Delta \log s$ |
|---|---|---|---|---|---|---|---|---|
| | $h_1$ | $h_2$ | $s_1 \frac{cm}{cm_3} 0°$ | $s_2 \frac{cm}{cm^3} 0°$ | | | | |
| | *Microvolt.* | *Microvolt.* | *Microhm.* | *Microhm.* | | | | |
| *l* | 5.0 | 19.6 | 14.0 | 47.5 | 14.6 | 33.5 | ..... | ..... |
| *s* | 6.9 | 15.1 | 16.0 | 34.9 | 8.2 | 18.9 | ..... | ..... |
| *m* | 6.0 | 17.3 | 15.0 | 41.2 | 11.3 | 26.2 | 460 | 440 |

From the remarks made in the above it follows obviously that the magnitude of the interval *II–I* will depend very essentially on the degree of carburation of the steel tested. We experimented with silver steel[158] of excellent quality. But commercial varieties of steel may be readily found in which the said interval *II–I* is even less than one-half that given in the table.

## CAST-IRON.

*Thermo-electric data.*—In his experiments on cast-iron Joule[159] found that the difference of thermo-electric position between state *I* and state *II* is about $\frac{1}{200}$ of the thermo-electric interval bismuth-antimony. In case of steel he found the change of thermo-electric position *II–I* to be in the same sense as in cast-iron and as large as $\frac{1}{15}$ of the said interval. Furthermore, "that the metal (cast-iron) is brought nearer bismuth (i. e., thermo-electric hardness is increased) as the quantity of carbon in combination is increased," and in much larger ratio than would be commensurate with the additional amounts of carbon.

[158] For silver steel see Percy, op. cit., pp. 237–240; also Faraday and Stoddard, Quar. Jour. Science, 1820, p. 325.

[159] Joule: l. c., p. 96.

As accurate a knowledge as possible of the electrical qualities of cast-iron is a matter of such importance as to call for a special examination of a variety of products. These were made with as much material as we found available. The results for thermo-electric power are given in the following tables (78–79), where $e$ denotes the electromotive force referred to silver in microvolts, observed or calculated as specified, corresponding to the temperature $T$ and $t$ of the junctions. On the basis of the formula of Avenarius, $e = a(T-t)+b(T^2-t^2)$, the constants $a$ and $b$ were calculated, usually from five sets of observations, by an application of the method of least squares. In how far the measurements are satisfactory may be seen by consulting the column of differences (Diff.) between $e$ observed and $e$ calculated. Rods No. 1, 2, 3 were of German cast iron; No. 1 soft and of excellent quality; Nos. 2 and 3, though also of good iron, so hard[160] as not to yield readily to a file. White cast-iron cannot be put in the form necessary for measurements like the present without encountering very great mechanical difficulties. But its properties are well represented by rods Nos. 2, 3, which were specially cast thin. Rods No. 4 . . . 12 are of good American cast-iron, so soft as to be easily touched with a file. They were planed down to approximately square and uniform sections for us by Mr. William Grunow, of New York. All the rods were examined in three states: the original or commercial condition in which they reached our hands; after sudden cooling from red heat (*II*); after annealing soft at red heat (*I*).[161] We considered chemical analyses superfluous for the reasons given near the beginning of this paper. A few isolated results of this kind are valueless.

TABLE 78.—*Thermo-electric power of cast-iron. German material.*

| Rod. | Remarks. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|---|
| | | ° C. | ° C. | *microvolt.* | *microvolt.* | | | |
| 1 | Original condition, soft | 19.2 | 83.4 | −385.5 | −386.4 | 0.9 | −4.94 | −0.0126 |
| | | 19.8 | 70.1 | −296.9 | −296.0 | −0.9 | | |
| | | 19.9 | 59.9 | −230.8 | −231.1 | 0.3 | | |
| | | 20.1 | 50.2 | −171.7 | −171.0 | −0.7 | | |
| | | 20.3 | 40.2 | −110.7 | −111.0 | 0.3 | | |
| | Suddenly cooled (II), hard | 15.7 | 59.9 | −342.2 | −342.8 | −0.4 | −7.04 | −0.0095 |
| | | 15.9 | 51.6 | −274.1 | −274.1 | 0.0 | | |
| | | 16.0 | 44.4 | −215.8 | −216.1 | 0.3 | | |
| | | 16.1 | 37.9 | −164.3 | −164.7 | 0.4 | | |
| | | 16.2 | 32.2 | −120.3 | −120.0 | −0.3 | | |
| | Annealed at red heat (I) | Rod broken. Too short for measurement. | | | | | | |
| 2 | Original condition, hard | 16.7 | 76.9 | −512.6 | −512.3 | −0.3 | −7.39 | −0.0067 |
| | | 16.7 | 69.5 | −446.2 | −446.6 | 0.4 | | |
| | | 16.8 | 59.7 | −360.2 | −360.1 | −0.1 | | |
| | | 16.8 | 49.9 | −275.5 | −275.7 | 0.2 | | |
| | | 16.8 | 39.1 | −184.2 | −184.1 | −0.1 | | |

[160] Rods Nos. 2 and 3 being only 0.2 . . 0.3 cm. in diameter, it was found impossible to cast them without the appearance of a steel-like and brittle hardness.

[161] Cf. Chapter II, p. 60.

TABLE 78.—*Thermo-electric power of cast-iron. German material*—Continued.

| Rod. | Remarks. | *t* | *T* | *e* observed. | *e* calculated. | Diff. | *a* | *b* |
|---|---|---|---|---|---|---|---|---|
| | | ° C. | ° C. | *microvolt.* | *microvolt.* | | | |
| 2 | Suddenly cooled (II), hard.. | 18.1 | 55.2 | —339.7 | —341.0 | 1.3 | —8.30 | —0.0121 |
| | | 18.1 | 49.6 | —289.2 | —287.5 | —1.7 | | |
| | | 18.0 | 44.7 | —236.4 | —237.1 | 0.7 | | |
| | | 18.0 | 39.3 | —192.4 | —191.7 | —0.7 | | |
| | | 18.0 | 34.8 | —149.8 | —150.3 | 0.5 | | |
| | Annealed at red heat (I), hard | 17.5 | 84.5 | —551.9 | —551.7 | —0.2 | —6.84 | —0.0126 |
| | | 17.5 | 74.5 | —461.6 | —461.6 | 0.0 | | |
| | | 17.6 | 63.9 | —368.1 | —368.3 | 0.2 | | |
| | | 17.6 | 54.2 | —291.4 | —291.3 | —0.1 | | |
| | | 17.7 | 42.9 | —193.3 | —193.2 | —0.1 | | |
| 3 | Original condition, hard | 17.8 | 79.8 | —526.0 | —527.2 | 1.2 | —8.06 | —0.0063 |
| | | 17.9 | 70.8 | —446.4 | —448.2 | 1.8 | | |
| | | 18.0 | 59.7 | —354.5 | —350.9 | —3.6 | | |
| | | 18.1 | 49.3 | —261.1 | —261.3 | 0.2 | | |
| | | 18.2 | 39.6 | —187.6 | —178.3 | 0.7 | | |
| | Suddenly cooled (II), hard | 17.9 | 58.8 | —377.2 | —377.8 | 0.6 | —8.12 | —0.0145 |
| | | 17.9 | 52.6 | —318.4 | —317.4 | —1.0 | | |
| | | 17.8 | 46.1 | —255.7 | —256.1 | 0.4 | | |
| | | 17.8 | 38.9 | —189.0 | —188.8 | —0.2 | | |
| | | 17.8 | 33.0 | —140.1 | —140.2 | 0.1 | | |
| | Annealed at red heat (I), hard | 18.0 | 88.2 | —569.2 | —568.4 | —0.8 | —6.61 | —0.0149 |
| | | 18.0 | 78.6 | —481.6 | —482.6 | 1.0 | | |
| | | 18.1 | 66.4 | —376.7 | —377.1 | 0.4 | | |
| | | 18.1 | 52.2 | —259.6 | —259.1 | —0.5 | | |
| | | 18.1 | 44.9 | —200.6 | —200.8 | 0.2 | | |

TABLE 79.—*Thermo-electric power of cast-iron. American material.*

| Rod. | Remarks. | *t* | *T* | *e* observed. | *e* calculated. | Diff. | *a* | *b* |
|---|---|---|---|---|---|---|---|---|
| | | ° C. | ° C. | *microvolt.* | *microvolt.* | | | |
| 4 | Original condition, soft | 24.0 | 89.0 | —500 | —499 | —1 | —5.88 | —0.0138 |
| | | 24.4 | 74.7 | —374 | —375 | 1 | | |
| | | 25.0 | 49.9 | —175 | —176 | 1 | | |
| | | 25.1 | 39.9 | —103 | —102 | —1 | | |
| | | 23.3 | 31.6 | — 56 | — 56 | 0 | | |
| | Suddenly cooled (II), hard | 20.5 | 55.6 | —245.0 | —244.7 | —0.3 | —6.42 | —0.0073 |
| | | 20.4 | 49.5 | —201.5 | —201.6 | 0.1 | | |
| | | 20.2 | 43.5 | —159.0 | —160.4 | 1.4 | | |
| | | 20.2 | 38.9 | —129.0 | —128.1 | —0.9 | | |
| | | 20.1 | 32.4 | — 83.5 | — 83.6 | 0.1 | | |
| | Annealed at red heat (I), soft | 19.1 | 88.7 | —428.7 | —429.7 | 1.0 | —4.42 | —0.0162 |
| | | 19.1 | 77.5 | —351.2 | —349.5 | —1.7 | | |
| | | 19.1 | 62.1 | —246.0 | —246.6 | 0.6 | | |
| | | 19.2 | 53.8 | —193.0 | —193.8 | 0.8 | | |
| | | 19.3 | 42.1 | —123.8 | —123.4 | —0.4 | | |
| 5 | Original condition, soft | 12.8 | 80.8 | —486 | —484 | —2 | —5.96 | —0.0123 |
| | | 13.1 | 68.0 | —380 | —382 | 2 | | |
| | | 13.4 | 56.0 | —290 | —290 | 0 | | |
| | | 13.7 | 47.0 | —224 | —223 | —1 | | |
| | | 13.9 | 35.2 | —140 | —140 | 0 | | |
| | Suddenly cooled (II), hard | 13.5 | 55.8 | —315.6 | —317.1 | 1.5 | —6.78 | —0.0164 |
| | | 14.0 | 49.8 | —268.2 | —266.4 | —1.8 | | |
| | | 14.3 | 39.6 | —184.6 | —185.6 | 1.0 | | |
| | | 14.6 | 33.4 | —137.5 | —136.8 | —0.7 | | |
| | | 15.0 | 27.6 | — 90.7 | — 91.0 | 0.3 | | |
| | Annealed at red heat (I), soft | 16.0 | 79.0 | —360.5 | —361.3 | 0.8 | —4.21 | —0.0161 |
| | | 16.4 | 65.7 | —274.5 | —272.4 | —2.1 | | |
| | | 16.7 | 56.6 | —213.1 | —214.8 | 1.7 | | |
| | | 17.0 | 43.9 | —140.1 | —139.4 | —0.7 | | |
| | | 17.4 | 35.3 | — 90.3 | — 90.5 | 0.2 | | |
| 6 | Original condition, soft | 14.9 | 83.2 | —462 | —462 | 0 | —5.22 | —0.0145 |
| | | 15.3 | 75.4 | —399 | —400 | 1 | | |
| | | 15.5 | 63.2 | —310 | —309 | —1 | | |
| | | 15.6 | 50.0 | —215 | —216 | 1 | | |
| | | 15.7 | 39.6 | —147 | —147 | 0 | | |

TABLE 79.—*Thermo-electric power of cast-iron. American material*—Continued.

| Rod. | Remarks. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|---|
| | | °C. | °C. | *microvolt.* | *microvolt.* | | | |
| 6 | Suddenly cooled (II), hard.. | 14.4 | 57.7 | —270.6 | —269.7 | —0.9 | —5.17 | —0.0147 |
| | | 15.0 | 48.9 | —206.6 | —207.1 | 0.5 | | |
| | | 15.3 | 40.7 | —151.4 | —152.2 | 0.8 | | |
| | | 15.9 | 34.8 | —111.7 | —111.8 | 0.1 | | |
| | | 16.2 | 29.4 | — 77.4 | — 77.1 | —0.3 | | |
| | Annealed at red heat (I), soft | 22.8 | 83.3 | —361.2 | —361.6 | 0.4 | —4.27 | —0.0161 |
| | | 23.0 | 75.2 | —306.0 | —305.4 | —2.6 | | |
| | | 23.0 | 63.2 | —225.5 | —227.4 | 1.9 | | |
| | | 23.0 | 53.3 | —168.7 | —169.5 | 0.8 | | |
| | | 23.0 | 41.5 | — 98.8 | — 98.1 | —0.7 | | |
| 7 | Original condition, soft .... | 18.2 | 71.9 | —372 | —371 | —1 | —5.72 | —0.0122 |
| | | 18.3 | 67.3 | —335 | —336 | 1 | | |
| | | 18.4 | 58.8 | —273 | —272 | —1 | | |
| | | 18.6 | 51.3 | —217 | —217 | 0 | | |
| | | 18.6 | 44.5 | —170 | —170 | 0 | | |
| | Suddenly cooled (II), hard, warped. | 14.7 | 57.9 | —321.2 | —320.4 | —0.8 | —6.29 | —0.0155 |
| | | 15.2 | 50.6 | —260.0 | —258.8 | —1.2 | | |
| | | 15.6 | 43.0 | —195.2 | —197.3 | 2.1 | | |
| | | 16.0 | 37.1 | —149.5 | —150.1 | 0.6 | | |
| | | 16.4 | 31.7 | —108.6 | —107.7 | —0.9 | | |
| | Annealed at red heat (I), soft | 21.4 | 82.6 | —359.0 | —358.9 | —0.1 | —4.33 | —0.0148 |
| | | 21.4 | 69.4 | —272.3 | —272.1 | —1.2 | | |
| | | 21.0 | 58.5 | —189.5 | —191.2 | 1.7 | | |
| | | 21.6 | 47.0 | —135.6 | —135.6 | 0.0 | | |
| | | 21.6 | 39.5 | — 94.0 | — 93.6 | —0.4 | | |
| 8 | Original condition, soft ..... | 17.4 | 86.9 | —502 | —500 | —2 | —5.34 | —0.0178 |
| | | 17.4 | 80.5 | —445 | —447 | 2 | | |
| | | 17.4 | 72.3 | —382 | —381 | —1 | | |
| | | 17.0 | 52.9 | —236 | —236 | 0 | | |
| | | 17.0 | 38.9 | —139 | —139 | 0 | | |
| | Suddenly cooled (II), not very hard. | 17.5 | 57.1 | —261.6 | —259.8 | —1.8 | —5.60 | —0.0129 |
| | | 17.9 | 50.8 | —212.0 | —213.3 | 1.3 | | |
| | | 18.2 | 45.3 | —172.1 | —173.9 | 1.8 | | |
| | | 18.7 | 40.1 | —137.2 | —136.0 | —1.2 | | |
| | | 19.0 | 35.4 | —103.4 | —103.3 | —0.1 | | |
| | Annealed at red heat (I), soft | 10.5 | 87.7 | —437.3 | —436.9 | —0.4 | —4.08 | —0.0166 |
| | | 10.8 | 75.3 | —350.7 | —352.0 | 1.3 | | |
| | | 11.1 | 62.9 | —274.8 | —272.3 | —2.5 | | |
| | | 11.2 | 52.0 | —205.7 | —207.2 | 1.5 | | |
| | | 11.5 | 42.7 | —154.1 | —153.7 | —0.4 | | |
| 9 | Original condition, soft ..... | 12.7 | 72.3 | —411 | —411 | 0 | —5.72 | —0.0138 |
| | | 12.8 | 64.0 | —347 | —347 | 0 | | |
| | | 12.8 | 52.2 | —262 | —261 | —1 | | |
| | | 12.9 | 43.0 | —195 | —196 | 1 | | |
| | | 12.9 | 37.0 | —154 | —154 | 0 | | |
| | Suddenly cooled (II), hard, fissured, warped. | 18.9 | 58.3 | —300.4 | —299.5 | —0.9 | —6.54 | —0.0127 |
| | | 19.2 | 52.6 | —251.1 | —251.4 | 0.3 | | |
| | | 19.5 | 44.9 | —187.2 | —188.7 | 1.5 | | |
| | | 19.9 | 37.1 | —126.6 | —126.0 | —0.6 | | |
| | | 20.2 | 33.6 | — 97.5 | — 97.0 | —0.5 | | |
| | Annealed at red heat (I), soft | 16.2 | 89.8 | —457.8 | —454.5 | —3.3 | —3.96 | —0.0208 |
| | | 16.4 | 81.8 | —388.1 | —393.1 | 5.0 | | |
| | | 16.6 | 72.5 | —327.7 | —325.6 | —2.1 | | |
| | | 16.8 | 60.7 | —245.2 | —245.1 | —0.1 | | |
| | | 16.9 | 51.6 | —187.3 | —187.3 | 0.0 | | |
| 10 | Original condition, soft ..... | 19.4 | 86.4 | —473 | —472 | —1 | —5.51 | —0.0145 |
| | | 19.3 | 73.6 | —372 | —372 | 0 | | |
| | | 19.1 | 56.1 | —243 | —244 | 1 | | |
| | | 18.8 | 43.8 | —160 | —160 | 0 | | |
| | | 18.7 | 35.0 | —103 | —102 | —1 | | |
| | Suddenly cooled (II), hard.. | 23.4 | 57.8 | —235.3 | —234.8 | —0.5 | —5.95 | —0.0108 |
| | | 23.4 | 50.9 | —185.0 | —185.6 | 0.6 | | |
| | | 23.5 | 47.1 | —157.3 | —158.3 | 0.5 | | |
| | | 23.7 | 42.6 | —126.5 | —126.0 | —0.5 | | |
| | | 23.8 | 37.4 | — 89.8 | — 89.9 | 0.1 | | |

TABLE 79.—*Thermo-electric power of cast iron. American material*—Continued.

| Rod. | Remarks. | $t$ | $T$ | $e$ observed. | $e$ calculated. | Diff. | $a$ | $b$ |
|---|---|---|---|---|---|---|---|---|
| | | °C. | °C. | *microvolt.* | *microvolt.* | | | |
| 10 | Annealed at red heat (I), soft. | 20.1 | 86.2 | −353.8 | −356.2 | 2.4 | −4.12 | −0.0168 |
| | | 20.0 | 78.3 | −335.1 | −333.0 | −2.1 | | |
| | | 19.1 | 69.2 | −275.7 | −274.2 | −1.5 | | |
| | | 19.7 | 59.6 | −214.5 | −215.6 | 1.1 | | |
| | | 19.6 | 50.1 | −160.0 | −160.0 | 0.0 | | |
| 11 | Original condition, soft | 21.6 | 74.9 | −364 | −364 | 0 | −5.59 | −0.0129 |
| | | 21.6 | 67.4 | −309 | −308 | −1 | | |
| | | 21.5 | 60.3 | −258 | −258 | 0 | | |
| | | 21.4 | 51.4 | −195 | −196 | 1 | | |
| | | 21.4 | 43.3 | −141 | −141 | 0 | | |
| | Suddenly cooled (II), hard | 25.8 | 57.6 | −234.8 | −234.6 | −0.2 | −6.98 | −0.0254 |
| | | 25.7 | 50.5 | −181.1 | −182.0 | 0.9 | | |
| | | 25.6 | 46.3 | −151.7 | −151.4 | −0.3 | | |
| | | 25.6 | 42.6 | −124.7 | −124.1 | −0.6 | | |
| | | 25.5 | 36.8 | − 81.8 | − 82.1 | 0.3 | | |
| 12 | Annealed at red heat (I), soft. | 19.0 | 89.6 | −329.1 | −329.9 | 1.8 | −3.82 | −0.0158 |
| | | 19.0 | 80.3 | −331.1 | −329.6 | −1.5 | | |
| | | 18.8 | 67.8 | −254.3 | −253.8 | −0.5 | | |
| | | 18.7 | 60.6 | −211.8 | −212.2 | 0.4 | | |
| | | 18.5 | 51.6 | −162.6 | −162.9 | 0.3 | | |
| | Original condition, soft | 22.5 | 86.2 | −449 | −449 | 0 | −5.53 | −0.0139 |
| | | 22.5 | 75.9 | −369 | −368 | −1 | | |
| | | 22.5 | 63.9 | −279 | −279 | 0 | | |
| | | 22.4 | 51.6 | −190 | −192 | 2 | | |
| | | 22.4 | 40.7 | −118 | −117 | −1 | | |
| | Suddenly cooled (II), hard | 12.1 | 57.9 | −312.7 | −311.0 | −1.7 | −5.83 | −0.0157 |
| | | 12.5 | 50.0 | −249.5 | −250.8 | 1.3 | | |
| | | 12.7 | 44.5 | −208.9 | −210.3 | +1.4 | | |
| | | 13.1 | 38.2 | −164.3 | −164.0 | −0.3 | | |
| | | 13.2 | 34.3 | −137.3 | −136.7 | −0.6 | | |
| | Annealed at red heat (I), soft. | 19.5 | 87.9 | −399.4 | −399.9 | 0.5 | −4.34 | −0.0141 |
| | | 19.5 | 80.2 | −348.3 | −348.3 | 0.0 | | |
| | | 19.4 | 67.3 | −267.8 | −266.1 | −1.7 | | |
| | | 19.4 | 54.1 | −184.5 | −186.3 | 1.8 | | |
| | | 19.3 | 45.9 | −140.4 | −139.8 | −0.6 | | |

*Resistance.*—We give in the following table (80) the results for the electrical resistance of cast-iron. The rods are respectively identical to those for which the Tables 78 and 79 apply. Under $W$ are contained the resistances per meter of length at the temperature $t$, in ohms; under $q$ the two sides of the rectangular section of the rods, in centimeters; $s_t$ and $s$ are the specific resistances at $t^0$ and $0^0$, the reduction having been effected by aid of the constant $\alpha$, determined elsewhere.[163] The rods are tested in the three states: original or commercial; after sudden cooling from red heat (*II*); after annealing at red heat (*I*).

[163] Cf. Chapter I, p. 22.

TABLE 80.—*Electrical resistance of cast-iron.*

GERMAN IRON.

| Rod. | Condition. | $W$ 1m | $t$ | $q$ | $s\frac{cm}{cm^2}\delta^0$ | $a$ | $s\frac{cm}{cm^3}0^0$ |
|---|---|---|---|---|---|---|---|
| | | *ohm.* | °C. | *cm²* | *microhm.* | | *microhm.* |
| 1 | Original state | 0.01235 | 16.0 | 0.771 · 0.771 | 78.4 | 0.0013 | 71.9 |
| | Suddenly cooled (II) | 1537 | 11.2 | 0.771 · 0.771 | 91.4 | 12 | 90.2 |
| | Thoroughly annealed (I) | 1070 | 14.5 | 0.758 · 0.758 | 61.5 | 13 | 60.4 |
| 2 | Original state | 0.0729 | 15.5 | 0.309 · 0.309 | 69.8 | 0.0013 | 68.4 |
| | Suddenly cooled (II) | 791 | 10.6 | 0.309 · 0.309 | 75.8 | 13 | 74.8 |
| | Thoroughly annealed (I) | 674 | 14.5 | 0.297 · 0.297 | 59.5 | 13 | 58.4 |
| 3 | Original state | 0.0750 | 15.5 | 0.307 · 0.307 | 70.6 | 0.0013 | 69.2 |
| | Suddenly cooled (II) | 790 | 11.4 | 0.307 · 0.307 | 74.4 | 13 | 73.3 |
| | Thoroughly annealed (I) | 688 | 14.5 | 0.293 · 0.293 | 58.8 | 13 | 57.7 |

AMERICAN IRON.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4 | Original state | 0.00981 | 23 | 0.977 · 0.936 | 89.7 | 0.0012 | 87.3 |
| | Suddenly cooled (II) | 1200 | 29 | 0.977 · 0.936 | 109.7 | 12 | 106.0 |
| | Thoroughly annealed (I) | 0848 | 16 | 0.977 · 0.936 | 77.5 | 12 | 76.1 |
| 5 | Original state | 0.00991 | 25 | 0.959 · 0.957 | 91.0 | 0.0012 | 88.2 |
| | Suddenly cooled (II) | 1244 | 25 | 0.959 · 0.957 | 114.2 | 12 | 110.9 |
| | Thoroughly annealed (I) | 0872 | 16 | 0.959 · 0.957 | 80.0 | 12 | 78.5 |
| 6 | Original state | 0.00981 | 25 | 0.951 · 0.950 | 84.1 | 0.0012 | 81.6 |
| | Suddenly cooled (II) | 1025 | 29 | 0.951 · 0.950 | 92.6 | 12 | 89.5 |
| | Thoroughly annealed (I) | 0877 | 16 | 0.051 · 0.950 | 79.3 | 12 | 77.3 |
| 7 | Original state | 0.01377 | 23 | 0.813 · 0.803 | 89.9 | 12 | 87.5 |
| | Suddenly cooled (II) | 1720 | 25 | 0.813 · 0.803 | 112.3 | 12 | 109.0 |
| | Thoroughly annealed (I) | 1214 | 16 | 0.813 · 0.803 | 79.2 | 12 | 77.7 |
| 8 | Original state | 0.01352 | 25 | 0.807 · 0.805 | 87.8 | 0.0012 | 85.6 |
| | Suddenly cooled (II) | 1561 | 29 | 0.807 : 0.805 | 101.4 | 12 | 98.0 |
| | Thoroughly annealed (I) | 1267 | 20 | 0.807 . 0.805 | 82.3 | 12 | 80.4 |
| 9 | Original state | 0.01403 | 25 | 0.790 · 0.789 | 87.4 | 0.0012 | 84.9 |
| | Suddenly cooled (II) | 1720 | 18 | 0.790 · 0.789 | 107.2 | 12 | 104.9 |
| | Thoroughly annealed (I) | 1265 | 16 | 0.790 · 0.789 | 78.9 | 12 | 77.4 |
| 11 | Original state | 0.02072 | 23 | 0.656 · 0.640 | 87.0 | 0.0012 | 84.7 |
| | Suddenly cooled (II) | 2510 | 25 | 0.656 · 0.640 | 105.4 | 12 | 102.3 |
| | Thoroughly annealed (I) | 1950 | 20 | 0.656 · 0.640 | 81.9 | 12 | 80.0 |
| 11 | Original state | 0.02173 | 25 | 0.643 · 0.642 | 89.7 | 0.0012 | 87.1 |
| | Suddenly cooled (II) | 2662 | 18 | 0.643 · 0.642 | 109.9 | 12 | 107.5 |
| | Thoroughly annealed (I) | 2075 | 20 | 0.643 · 0.642 | 85.7 | 12 | 83.7 |
| 12 | Original state | 0.02173 | 25 | 0.647 · 0.646 | 90.8 | 0.0012 | 88.2 |
| | Suddenly cooled (II) | 2624 | 25 | 0.647 · 0.646 | 109.7 | 12 | 106.5 |
| | Thoroughly annealed (I) | 2060 | 20 | 0.647 · 0.646 | 86.1 | 12 | 84.1 |

*Digest.*—In the following table the important results in Tables 78, 79 and 80, above, are systematically arranged for convenience in reference. It will be at once intelligible. We need only remark that in case of No. 1 the measurement of $a$ was no longer possible for the soft annealed ($I$) condition, the rod having been accidentally broken. For this reason the value of $a$ for the original state is taken for $a_1$ in the formation of $\Delta a$, and $\Delta h$. This, however, is quite permissible since the rod was originally soft. It may be added that in the tables the logarithms are primarily deduced, the antilogarithms from these. This table furnishes us with mean values for cast-iron. They are given in the final horizontal row.

TABLE 81.—*Electrical constants of cast-iron.*

| Rod. | Thermoel. constant $a$, referred to soft silver, for $\frac{1}{2}(T+t)=0$ (in microvolt). | | | Thermoel. hardness, deduced from $a$ and $h=15.18-a$, for $\frac{1}{2}(T+t)=0$ (in microvolts). | | | | | | Specific electrical resistance $s\frac{\text{cm}}{\text{cm}^3}$ (in microhms). | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $a_1$ | $a_2$ | $\Delta a$ | $h_1$ | $h_2$ | $\Delta h$ | $\log h_1$ | $\log h_2$ | $10^3\Delta \log h$ | $s_1$ | $s_2$ | $\Delta s$ | $\log s_1$ | $\log s_2$ | $10^3\Delta \log s$ |
| No. 1 | (—4.94) | —7.04 | 2.10 | (20.12) | 22.22 | 2.10 | 1.3036 | 1.3467 | 43.1 | 60.4 | 90.2 | 29.8 | 1.7809 | 1.9551 | 174 |
| No. 2 | —6.34 | —8.30 | 1.46 | 22.02 | 23.48 | 1.46 | .3428 | .3707 | 27.9 | 58.4 | 74.8 | 16.4 | .7663 | .8736 | 107 |
| No. 3 | —6.61 | —8.12 | 1.51 | 21.79 | 23.30 | 1.51 | .3383 | .3674 | 29.1 | 57.7 | 73.3 | 15.6 | .7610 | .8651 | 104 |
| No. 4 | —4.42 | —6.42 | 2.00 | 19.60 | 21.60 | 2.00 | .2923 | .3345 | 42.2 | 76.1 | 106.0 | 29.9 | .8812 | .0255 | 144 |
| No. 5 | —4.21 | —6.78 | 2.57 | 19.39 | 21.96 | 2.57 | .2876 | .3416 | 54.0 | 78.5 | 110.9 | 32.4 | .8949 | .0448 | 150 |
| No. 6 | —4.27 | —5.17 | 0.90 | 19.45 | 20.35 | 0.90 | .2889 | .3086 | 19.7 | 77.2 | 89.5 | 11.7 | .8907 | .9517 | 61 |
| No. 7 | —4.32 | —6.29 | 1.97 | 19.50 | 21.47 | 1.97 | .2900 | .3318 | 41.8 | 77.7 | 109.0 | 31.3 | .8906 | .0375 | 147 |
| No. 8 | —4.08 | —5.60 | 1.57 | 19.21 | 20.78 | 1.57 | .2835 | .3176 | 34.1 | 80.4 | 98.0 | 17.6 | .9052 | .9911 | 86 |
| No. 9 | —3.98 | —6.54 | 2.56 | 19.16 | 21.72 | 2.56 | .2824 | .3369 | 54.5 | 77.4 | 104.9 | 27.5 | .8885 | .0209 | 132 |
| No. 10 | —4.12 | —5.95 | 1.83 | 19.30 | 21.13 | 1.83 | .2856 | .3249 | 39.3 | 80.0 | 102.3 | 22.3 | .9029 | .0100 | 107 |
| No. 11 | —3.83 | —6.93 | 3.10 | 19.01 | 22.11 | 3.10 | .2790 | .3446 | 65.6 | 83.7 | 107.5 | 23.8 | .9225 | .0316 | 109 |
| No. 12 | —4.34 | —5.83 | 1.49 | 19.52 | 21.01 | 1.49 | .2905 | .3224 | 31.9 | 84.1 | 106.5 | 22.4 | .9246 | .0273 | 103 |
| Means | —4.66 | —6.58 | 1.92 | 19.84 | 21.76 | 1.92 | ..... | ..... | 40.3 | 74.4 | 97.8 | 23.4 | ..... | ..... | 119 |

## DISCUSSION.

*Plane diagram.*—The experimental material in hand is sufficient for the discernment of the main and characteristic features of the relation which exists between the mechanical and chemical properties of iron-carburets, and their electrical behavior. We will arrive at our end soonest by proceeding graphically, using as the basis for our construction the general mean values given in Tables 76–77 and at the end of Table 81. As regards the interpretation of these data we derive very valuable clews from our earlier researches on the electrical properties of alloys. If to a given metal small amounts of a second metal be alloyed, the electrical constants are found to vary in a uniformly continuous way. Now, the total carbon in steel amounts to only 1–2 per cent; in cast iron to less than 5 per cent. We may therefore predict a mode of variation of specific resistances and thermo-electric power which shall be analogous to that observed for alloys. In other words, a uniformly continuous change in the electrical qualities of iron-carburets with the amount of carbon contained may justifiably be assumed. With the ultimate object in view of developing our diagram, let the percentage of total carbon, therefore, be represented as abscissa, the electrical constants $h$ and $s$ as ordinate. Carbon, however, occurs differently in iron-carburets when in the condition *I* than when in the other extreme condition, *II*. It is therefore necessary sharply to distinguish between the constants $h_1$ and $s_1$ belonging to the first or thoroughly annealed state, and the constants $h_2$ and $s_2$ for the hard state. Our data therefore furnish points belonging to two essentially different loci. Unfortunately for each of these, only three such points are in hand: the first

corresponding to wrought-iron and the abscissa, $x=0$; the second to steel where, approximately, $x=1.5$; the third to cast-iron, where we may roughly put $x=5.0$. The mean values of ordinate belonging to these abscissæ may be taken from the following little table:

TABLE 82.—*Mean electrical constants of iron-carburets.*

| Material. | $x$ | $h_1$ | $h_2$ | $\Delta h$ | $10^3 \times \Delta \log h$ | $s_1$ | $s_2$ | $\Delta s$ | $10^3 \times \Delta \log s$ |
|---|---|---|---|---|---|---|---|---|---|
| Wrought iron | 0 | 4.7 | 4.7 | zero | zero | 12.2 | 12.2 | zero | zero |
| Steel | 1.5 | 6.0 | 17.3 | 11.3 | 460 | 15.0 | 41.2 | 26.2 | 440 |
| Cast iron | 5.0 | 19.8 | 21.8 | 1.9 | 40 | 74.4 | 97.8 | 23.4 | 120 |

With these data and the qualitative results just referred to, our attention will be first directed to the hard state, *II*, of iron-carburets. Between $x=0$ (iron), and $x=1.5$ (steel), iron-carburets vary in marked degree as regards hardness, a circumstance observable both in the mechanical and electrical properties ($h_2$, $s_2$) of these products. Beyond this, approaching castiron, the variations are slight. The curve rises rapidly at first, finally at a gradually decreasing rate, and is therefore as a whole concave towards the axis of abscissæ.

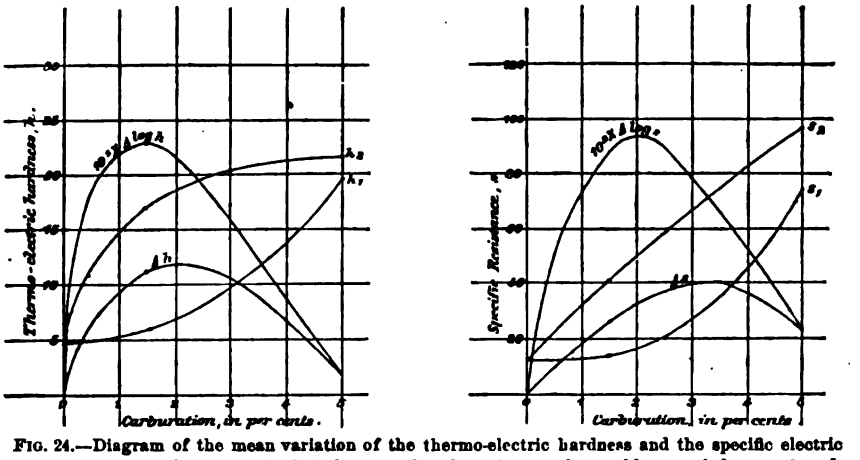



FIG. 24.—Diagram of the mean variation of the thermo-electric hardness and the specific electric resistance of iron-carburets, with their degrees of carburation; 1, thoroughly annealed state; 2, suddenly cooled state.

A result almost the inverse of this is encountered in the case of the "soft" state *I*. Here the initial variations are insignificant, soft iron and soft steel differing slightly, not only in their mechanical states of hardness, but also in the electrical manifestation ($h_1$, $s_1$) of this quality. It is not until we pass beyond $x=1.5$ and enter the region of the cast-irons that the present curve *I* rises at a relatively rapid or accelerated rate. The curves, *I*, are therefore on the whole convex as regards the axis of abscissæ.

From these points of view the curves in the above diagram $h_2$, $s_2$

and $h_1$, $s_1$ have been drawn. It may be plainly argued, moreover, that their general character does not change during the progress from $x=0$ to $x=5$; in other words, we accept concavity and convexity respectively throughout the given extent of the curves, to the exclusion of points of circumflexion. With this probable inference postulated, we observe that the two sets of curves $h_2$, $s_2$ and $h_1$, $s_1$ must intersect in the region of cast-iron, that is, near $x=5$.

Curiously enough we found in certain data of Joule[163] the evidence for such intersection. If we reduce Joule's figures to our scale of thermo-electric hardness, his results for white cast-iron and gray cast-iron are approximately these:

First extreme: cast-iron, black fracture (with much graphite), $h=25$.

Second extreme: cast-iron, white fracture (very hard), $h=12$. All other samples of cast-iron which he examined lay between these limits. The large values for $h$ and $s$ obtained[164] for malleable cast-iron (known to be graphitic[165]) are also in accordance with Joule's results. The first mentioned of the cast-irons above ($h=25$) is therefore to be referred to condition *I* (soft, carbon uncombined), the second ($h=12$, carbon combined, hard) to condition *II*, which gives evidence in favor of the intersection of the respective curves.

*Superimposed electrical effects.*—To this inversion of the electrical properties of iron-carburets as the quantity of total carbon is increased we have already adverted,[166] and it is therefore essential to any discussion of the phenomena before us to take cognizance of the mechanical as well as the chemical causes of the same. These are three in number: (1) Effect of uncombined carbon; (2) effect of combined carbon; (3) effect of the peculiar strain accompanying temper.

In the curves $h_1$ and $s_1$ the first of these factors is primarily active, the second of small importance, the third inactive. The material is approximately homogeneous. In the curves $h_2$ and $s_2$, however, all factors produce their own specific results, though the influence of the first is relatively small. Here, therefore, we are confronted by a complex superposition of effects; such however, that between wrought-iron and steel the mechanical cause (3) is almost solely efficient; between steel and cast-iron the chemical causes (1, 2) predominate.

*Character of $\Delta h$.*—As the result of the opposed character of the curvatures of the loci *I* (soft state) and *II* (hard state), the first being convex, the second concave, as regards the axis of abscissæ, we are able to draw an inference of fundamental importance. For if we put $\Delta h=h_2-h_1$ and $\Delta s=s_2-s_1$, then it follows obviously that the new variables $\Delta h$ and $\Delta s$, regarded as functions of $x$, must each pass through a maximum. This remarkable result may be formulated thus:

The diagram which expresses the electrical behavior of commercial

[163] Joule: l. c.

[164] Chapter III, p. 102.

[165] Forquignon: l. c.

[166] Chapter III, p. 103.

iron-carburets distinctly indicates the existence of a singular product, possessing the unique capability of occurrence in the greatest number possible of mechanical states—a member, in other words, for which the difference of thermo-electric hardness between condition *II* and condition *I* is a *maximum*. This is a necessary but not a sufficient condition for the definition of that valuable product to which the term "steel" is applicable. For, irrespective of the fact that $\Delta h$=max. and $\Delta s$=max. need not necessarily select the same product, a definition based solely on the absolute value of the interval of variation does not necessarily exclude the occurrence of any marked change of hardness as regards the soft state. Yet this is essential. The mere fact, in other words, that for the unique iron-carburet in question the state *II* is furthest removed with reference to hardness from the state *I*, might even be true of a product brittle in the latter (soft) state.

*Character of $\Delta \log h$.*—To meet this objectionable feature of the above definition, therefore, it is expedient to give preference not to the absolute variations of $h$ and $s$, but to the relative variations $h_2 : h_1$, $s_2 : s_1$, of pairs of values of $h$ and $s$. For this reason the *logarithmic* interval is considered. If $\Delta h = \log h_2 - \log h_1$ and $\Delta s = \log s_2 - \log s_1$, then we have for the definition of steel $\Delta \log h$=max., or $\Delta \log s$=max. Between these we have yet to decide. In the first place it is to be noted that the equations $\Delta h$=max. and $\Delta s$=max., determine $x=2$ and $x=3$, respectively, and so far as can as yet be foreseen; whereas $\Delta \log h$=max. and $\Delta \log s$=max., apply for $x=1.5$ and $x=2.0$, respectively. In the latter case, therefore, not only are the two carburets defined chemically much more nearly coincident, but their mean position in the diagram is such as to select from all the iron-carburets the one which may stand as a *type* for the products commercially termed steel. And we may add here that, in so far as the variation of a function like the one in hand in the neighborhood of a maximum is usually small, a group of iron carburets disposed on either side of the said maximum will possess properties sufficiently alike to enable us to consider them as practically and commercially identical with the accurately defined type. Now it is very probable, if material of sufficient purity could be obtained, that both the equations $\Delta \log h$=max. and $\Delta \log s$=max. will be found satisfiable by the same $x$, and this from the fact that as far as steel, at least, the relation between thermo-electric hardness and specific resistance is linear. But after subjecting any iron-carburet to the process of sudden cooling, the external layers will usually have been transferred into the state *II* more thoroughly than the core, particularly in case of thick rods and highly carburized iron. But it is from the external layers that $\Delta \log h$ is practically determinable, irrespective of the figure and dimensions of the carburet operated upon. $\Delta \log s$ is not readily determinable except for the mean condition of a carburet of definite figure.

*Definition of steel.*—Preference is, therefore, to be given to the former of the two critical equations and $\Delta \log h = \text{maximum}$ to be accepted as the physical definition of steel. This equation is to be interpreted thus:

Let each member of the whole series of non-carburets be subjected successively to the following two operations:

1. A process of very slow cooling from a given temperature in red heat.

2. A process of most rapid cooling possible from the same temperature.

If now the carburets be examined with reference to the hardness produced in the two instances, there will be found among them a certain unique member whose properties are such that while process *I* has more nearly identified it with pure soft iron; process *II* will have moved it farther away from this initial carburet[167] than is simultaneously the case with any other iron-carbon product; or which, in other words, is capable of occurring in the greatest number of states of hardness *relative to the soft state* possible. To this unique product the term "steel" is to be applied.

In so far, however, as the softest steel, for the very reason of its being essentially an iron-carburet, can never reach pure iron, it is obvious that there must remain a *difference* between the mechanical properties (Young's modulus, simple rigidity, tenacity, etc.) in general of soft iron and soft steel, on account of which preference will be given to one material or the other, as the needs of the engineer suggest. To this carburet ($\Delta \log h = \text{max.}$), finally, the maximum capacity for the retention of a strain of any given kind which may be imparted to it, seems also to belong. The strain accompanying magnetism, and the strain peculiar to hardness, of each of which steel retains a phenomenal amount, may be cited as examples.

## COMMERCIAL OR IMPURE IRON-CARBURETS.

*Series of iron-carburets.*—Thus far no attention has been paid to the unavoidable impurities like sulphur, silicon, phosphorus, manganese, etc., which in addition to carbon are always present in commercial iron-carbon products. But it is easy to extend the considerations just made in such a way as will make them applicable to iron-carburets, pure and impure, generally. Let any iron-carburet be given. To this belong a whole series of iron-carburets so constituted that, while in other respects the composition is identical throughout, carbon alone passes through the interval from zero to about six per cent.[168] To each such series (see

[167] That is, soft iron for which $x=0$.

[168] Of course, the increment in C in this case presupposes a decrement in total *Fe*, so that there may be no variation in the percentage presence of the impurities.

below, p. 191) a definite and characteristic pair of curves, $h_2$ and $h_1$, will correspond, and that particular impure iron-carburet which is selected by the equation

$$\Delta \log h = \text{maximum}$$

is *the* steel for the given class of impure iron-carbon products. These relations may be tersely exhibited as follows. Let

$$z_1 = f_1(a, b, c \ldots . x)$$

where $z_1$ denotes the thermo-electric hardness of a given sample of impure iron-carburet, $a$, $b$, $c$ . . . . , are parameters expressing the respective amounts of the impurities present in per cents. by weight of the whole, $x$ (independent variable) representing the total carbon present, also in per cents. of the whole.

Let

$$z_2 = f_2(a, b, c, \ldots x)$$

be interpreted in like manner. Now suppose the functions $z_1$ and $z_2$ to belong simultaneously to the same product, or in other words, to apply when the said given product is in the state *I* and the state *II*, respectively.[169] Then will these equations, if $x$ be allowed to increase continuously from zero to about six, express the critical electrical properties of the whole given series of impure iron-carburets. Again by varying any one or all of the parameters, $a$, $b$, $c$ . . ., we may pass from a given series of this kind to any other.[170] Finally the function, in the case of a given series,

$$\Delta \log z = \log z_2 - \log z_1$$

possesses the important property that for wrought iron its value approaches zero; for cast-iron its value is some positive number, and for steel we shall have $\Delta \log z = \text{maximum}$. In order to determine the position of any iron-carburet in its own series a knowledge of the functions $z_1$ and $z_2$ is fully sufficient.

*Thermo-electric hardness—general interpretation.*—With these new inferences we are able to give the results of an earlier chapter (II), a much more comprehensive interpretation. The extreme values of thermo-electric hardness, $z_1$ and $z_2$, corresponding to thorough annealing and sudden cooling, respectively, describe any given member of any given series of iron-carburets with reference to its chemical properties; *i. e.*, $z_1$ and $z_2$, together, determine its position in a diagram of classification peculiar to iron-carburets. The intermediate values of $z$, in other words, those lying between $z_1$ and $z_2$, and obtainable by the annealing of the previously chilled carburet, describe the same product with reference to its mechanical properties; *i. e.*, the value of $z$ deter-

[169] In practice $f_1$ and $f_2$ will be interpolatory functions of like character.

[170] It is to be borne in mind here that these remarks apply principally for iron-carburets, in which $x$ does not exceed 2. The final generalization is given below.

mines its position in a scale of hardness peculiar to the particular iron-carburet ($z_1$, $z_2$) in hand.

Herewith we have succeeded in expressing the general conception of a problem, of which our research on the hardness of steel (Chapter II) is to be regarded as only a special solution.[171]

## FINAL GENERALIZATION.

*Qualitative and quantitative carburation.*—In the above discussion the general features of the electrical behavior of iron carburets, whose degree of carburation is above 2 per cent., has already been given. But a more detailed consideration must take cognizance of the fact that even in case of the same chemical composition we encounter iron-carburets differing enormously in their physical properties, and we are led into a host of complications not readily to be surveyed. The mode of occurrence of carbon in iron, or what may be called the quality of carburation, becomes more and more dominant in effecting changes of physical character of these products, as the amount of total carbon present is increased. The temperature in red heat from which the conditions *I* (thoroughly annealed) and *II* (suddenly cooled) are reached, as well as the time during which exposure to the same takes place, here possesses essential importance.

*Classification-function.*—The prolongation of the critical curves $h_1$ and $h_2$ from steel into the region of cast-iron can therefore be made in a great variety of ways. For each particular path definite premises must be laid down, viz., that the increase of carbon shall take place, qualitatively as well as quantitatively, in a way such as is in accordance with the manner of carburation of the sample of cast-iron, in which the particular path in question is to terminate. Perhaps these relations are expressible with greater clearness in this wise: Suppose that with reference to the height and duration of the temperature from which thorough annealing (*I*) and sudden cooling (*II*) is to be effected, etc., certain fixed assumptions have been made. But beyond this let it be unrestricted, so that it may even lie beyond the melting point of the carburets operated upon. Furthermore, suppose the percentage amount (parameter) of foreign admixtures and impurities other than carbon present in iron be constant throughout. Then let the relations here involved be represented graphically in three dimensions: Thermo-electric hardness parallel to the axis $Z$; carburation quantitatively considered (percentage

[171] A good example of the difference between mechanical and thermo-electric hardness is given by malleable cast-iron, results for which are given elsewhere (Chapter III, p. 102).

of total carbon) parallel to the axis $X$; finally qualitative carburation,[172] *i. e.*, a quantity which expresses the mode of occurrence of carbon in iron, parallel to the axis $Y$. With this understanding a characteristic surface will correspond both to condition $I$ and condition $II$; and if analogously to the above (p. 189), we deduce the difference $\Delta \log z$, its form will be

$$\Delta \log z = F(a, b, c, \ldots . y, x)$$

where the parameters $a$, $b$, $c$, ... refer to the impurities present.

Every plane parallel to $XZ$ cuts this surface in a curve, expressing the electrical behavior of a series of iron carburets as above defined (p. 188). All such curves of intersection are characterized by the presence of a maximum defining the steel corresponding to the impure iron, $F(a, b, c, \ldots y, 0)$, the initial carburet of the particular series under consideration.

Every plane parallel to $YZ$ cuts the surface $\Delta \log z$ in a curve, expressing the electrical behavior of all carburets possible in case of a selected fixed amount of total carbon in the iron carburet. Two such curves will differ more as their distance apart as well as from the initial plane $YZ$ is greater. It will be seen that the further step in the present research must be that of suitably varying the elements of the operations $I$ and $II$[173] in such a way as to throw additional light on all these complications, among which those last mentioned are as yet the most obscure and imperfectly understood.

*Classification diagram.*—Notwithstanding the dangers encountered in representing views in part theoretical with the aid of a diagram, we are able to bring to the mind of the reader all that has been said so perspicuously in this way, as readily vindicates the venture of a rough construction of the probable contour of the surface $\Delta \log z$. In the following figure (25) the $XZ$ plane cuts the surface $\Delta \log z$ (*rstno*) in a line coinciding with the axis $X$. This is supposed to be an hypothetical carburet, iron-graphite, which remains iron-graphite both in state $I$ and in state $II$. The extreme plane parallel to $XZ$ represents the series of

[172] As an example of the nature of the variable $y$, suppose it, for instance, to be the mean ratio of combined to uncombined carbon for the two states, I and II, or, $y = \frac{1}{2}\left\{\left(\frac{\text{combined } C}{\text{uncombined } C}\right)_I + \left(\frac{\text{combined } C}{\text{uncombined } C}\right)_{II}\right\}$. Should a single quantity, $y$, be insufficient to express the qualitative occurrence of carbon, so that a number of such variables $y$, $y'$, $y''$, ..... are necessary, then while any given one, $y$ for instance, passes all values, the others are to be regarded as parameters—*i. e.*, constants during this variation. The presence of graphite, amorphous carbon, and combined carbon in iron may suggest two variables, $y$, $y'$.

[173] Much, for instance, could be learned from continuous electrical ignition of iron-carburets, in vacuo and gases, respectively, and examination of the test sample from time to time; more from a detailed exploration of these phenomena, made conjointly by a physicist and a chemist. Carburation produced by ignition in gaseous hydrocarbons, and subsequently in vacuo, suggests itself as a first convenient method of experimental attack.

iron-carburets (*rst*) in which all carbon is combined, at least in state *II*. White cast-iron may be supposed to belong to this series. The plane

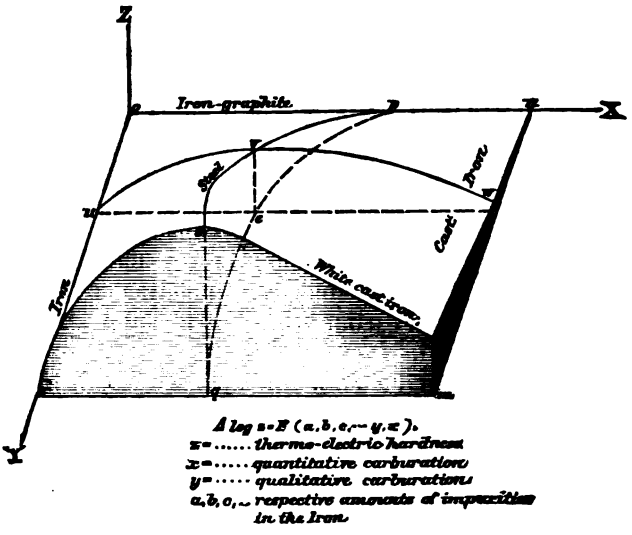



FIG. 25.—Classification diagram.

*YZ* intersects the surface $\Delta \log z$ in the iron line approximately coinciding with the axis *Y*. The extreme plane (*mtn*) parallel to *YZ* corresponds to about $x=6$. The most interesting feature of the diagram is the totality of steel maxima (*svp*). If ordinates be let fall from each of these, the resulting cylinder will intersect the plane *XY* in a curve (*peq*), expressing both qualitatively and quantitatively the carburation of the infinite steels possible in case of a given impure iron-carburet $F(a, b, c, \ldots y, x)$. It is hardly necessary to add that the number of such possible surfaces (*rstno*) is again infinite; since any variation of the parameters *a*, *b*, *c*,... or the accessary variables *y*,' *y*,''.. involves the construction of a new one. Practically, however, a finite number of typical surfaces suffice.

The figure finally contains an illustrative intermediate section, in which *v* is the steel of the series of iron-carburets *uvw*.

*Concluding remarks.*—The perusal of the above pages will have shown that the problem in hand, considered in its full generality, is exceedingly complicated. Nevertheless, we presume to believe that the method of attack which has been briefly developed in this chapter contains promise of success. Both the intimate relationship between the mechanical properties of iron-carburets and their electrical behavior, as well as the incomparable sensitiveness of the functions involved, emphatically commend our electrical diagram to the metallurgical engineer. Indeed, it is remarkable that metallurgists have thus far given no attention to a class of physical properties which, from their simplicity

and pronounced character, seem above all others to be adapted for purposes of discrimination and classification. Magnetic functions, as we have shown elsewhere, admit much less readily of satisfactory interpretation, varying as they do enormously with the figure and dimensions of the sample under examination. The interest of the present chapter, however, centers in the important product, steel. Curiously enough, the large range of variation of mechanical properties which renders this substance so indispensably useful have not as yet been found available for its accurate definition. The electrical qualities of steel, however, furnish a means to this end, which can conveniently be pushed to greater detail and nicety than will be necessary for any metallurgical or even physical purposes. It is in this respect that we believe with the present publication to have opened a new field of research, useful alike in its bearing on the practical and the theoretical problems concerning iron-carburets.

## CHAPTER VIII.

### BRIEF SUMMARY OF THE PRINCIPAL DATA.

*Introduction.*—The remarks in this memoir refer almost exclusively to the species of hardness known as temper, and which may be imparted to iron-carburets by sudden cooling from red heat combined with more or less subsequent annealing.

It falls within the scope of the work to develop so far as possible the very close analogy which exists between tempering and magnetization.

If we define the structure of a hard cylindrical steel rod as being the law of variation of density encountered on a passage from axis to circumference along any radius of the rod, then structural identity in case of two given geometrically similar rods of the same composition *a priori* implies identity of diameter. In what way structure may vary with diameter is not even conjecturable. It follows that immediately comparable maguetic data are to be anticipated only where the rods of variable hardness and length retain the same thickness and composition throughout the course of the experiments.

*Chapter I.*—Like the specific resistance, the galvanic temperature-coefficient of the iron-carburets exhibits a phenomenal range of variation, passing from the values for wrought iron and soft steel, 0.0052 and 0.0043, respectively, to the values for hard steel and cast iron, 0.0016 and 0.0013, respectively. The said coefficient decreases continuously and uniformly as resistance increases, more rapidly than the latter during the earlier stages, much more slowly during the later stages of a progress from iron to cast iron. An inferior limit of the temperature-coefficient would therefore seem to appear much before the iron-carburet reaches the superior limit of resistance. If classified with reference to the relation between resistance and temperature, the iron-carburets as a whole form one continuous series.

*Chapter II.*—If the temperature from which steel is suddenly cooled be supposed to increase continuously from a very low value to the highest admissible, the hardness of the chilled rod will remain comparatively inappreciable until a certain critical temperature in red heat is reached. At this stage and a little beyond hardness increases at exceedingly rapid rates with temperature, after which the rate again decreases.

The largest observed variation of thermo-electric power produced by

tempering is 12.8 microvolts per degree centigrade at 0°. The largest ratio of the respective resistances of hard and soft steel

$$45\ (\text{cm} / \text{cm}^2, 0^\circ, \text{microhm}) : 15\ (\text{cm} / \text{cm}^2, 0^\circ, \text{microhm}) = 3.$$

Since hard and soft steel lie on opposite sides of pure silver in the thermo-electric scale, maxima and neutral points of electromotive force (thermo-electric inversions) are a common occurrence.

The annealing effect of any temperature acting on glass-hard steel increases gradually at a rate diminishing continuously through infinite time—diminishing very slowly in case of low temperatures ($<100^\circ$), very rapidly at first, then again slowly in the case of high temperatures ($>200^\circ$); so that the highest and hardest of the inferior states of hardness possible at any given temperature is approached asymptotically.

The ultimate annealing effect of any temperature $t^\circ$ is independent of the possibly pre-existing effects of a temperature $t'^\circ$, and is not in any way influenced by subsequent application of the latter, provided $t > t'$. In case of partial annealing at $t^\circ$ (time finite) this law applies more fully the more nearly the said ultimate effect of $t^\circ$ is reached.

If hardness of steel is to be expressed thermo-electrically, it is inexpedient to use the soft state as a point of departure. The thermo-electric difference between soft steel and soft iron (say 1) when compared with the corresponding difference between the extreme states of steel (say 10) is small. In soft steel, however, the effect of foreign ingredients (impurities: S, P, Si, Mn, etc.) is still too pronounced to admit of a desirably accurate determination of the thermo-electric position[174] of this metal.

In the case of steel, the relation between thermo-electromotive force per degree centigrade at 0°, and specific resistance at 0° ($s$), is linear throughout the whole of the phenomenal range of variation of these qualities with hardness. This law suggests the introduction of the new variable *thermo-electric hardness* ($h$), defined thus: Suppose the said law of linear variation to be true indefinitely; then will the electromotive force (microvolt) per degree centigrade at 0° of a thermo-element consisting of steel in the imaginary normal state whose specific resistance (cm / cm³ 0° microhm) is zero, and steel in any given state, be the thermo-electric hardness of the latter. The thermo-electric position of steel in the stated normal condition, with reference to pure soft silver, is

$$m = 15.18 \text{ microvolts}$$

per degree C. at 0°. Finally in the fundamental equation $h = n\,s$,

$$n = 0.412$$

*Chapter III.*—The chemical theory of the phenomenon of temper leads to this ulterior inference. By the simple process of sudden cool-

[174] It may be added here that, even if chemically pure steel were available, its thermo-electric position would, very probably, be seriously variable in consequence of unknowable differences in the mode of occurrence of the carbon contained.

ing, combined with subsequent annealing, applied to steel, inasmuch as in this way, within certain limits, any given amount of an electrically active ingredient (carbon) may be converted into an electrically passive form, the same results are reached which in the case of alloys are obtainable only by melting the two component metals together.

In the case of alloys, the plane locus determined by thermo-electric power (microvolts) per degree centigrade, at 0°, and specific resistance (cm / cm² 0° microhm) shows maxima (or minima) for both properties, so disposed that the said singular points, at the temperature 0° at least, do not coincide. The range of variation of the electrical properties in question appears to increase with the difference of specific volume of the (two) ingredients of the alloy. Applied to steel, the results interpret the observed linear locus for the metal (steel) as being the initial tangent of a curve of comparatively enormous magnitude.

Variation of resistance is a necessary concomitant of variation of volume; no matter how the latter may have been produced—whether by temperature or by tempering—the increments of resistance ($s$) due to a given increment of volume ($v$) are of the same order. A purely thermal effect in the one case does not therefore appear. If we put

$$s_2 = s_1\left(1+k\frac{v_2-v_1}{v_1}\right)$$

$$k = \frac{s_2-s_1}{s_1} : \frac{v_2-v_1}{v_1} = 150, \text{ a first approximation.}$$

Gentle ignition after a previous state of (hard) temper appears to be generally accompanied by a passage of both resistance and volume through minima.

The annealing effect of temperature and time in the case of drawn hardness is quite analogous to the said effect in the case of temper.

The position of cast iron is isolated with respect to the locus expressing the simultaneous variation of thermo-electric power and specific resistance due to changes of temper in case of the other carburets (steel). Cf. this résumé, Chapter I.

The chemical theory does not suggest nor account for the observed phenomena of annealing. Considered physically these are at once referable to the category of viscous phenomena. In the ordinary cases of viscosity measurement, the phenomenon is evoked by sudden application of stress (torsion, flexure, tension, volume compression or extension, etc.) under conditions of constant viscosity; in the case of annealing, by sudden decrease of viscosity under conditions of initially constant stress. Thermal expansion interferes with the purity of these phenomena by destroying the conditions of existence of the characteristic strain which accompanies hardness, and this in proportion as the expansion is greater. The final evidence in favor of the given interpretation (viscosity) of the phenomena of annealing is this: that the maximum of permanent hardness which can in any way be imparted to steel

(*i. e.*, the maximum intensity of strain which a steel rod is of itself able to maintain) decreases rapidly as temperature increases. (Cf. Chap. III, p. 97.)

The temperature condition (cf. Chapter II of this résumé) to which the appearance of glass-hardness is subject, is readily suggested by the chemical theory. Physically the state of red heat of iron and of steel is remarkable for the occurrence of certain characteristic phenomena: sudden volume-expansion (Cumming); anomalous thermo-electric behavior (Tait); disappearance of the magnetic quality (Gore); sudden appearance of glass-hardness in steel chilled from this temperature (Chernoff). An anomalous variation of resistance may be additionally inferred. As regards conditions favorable to glass-hardness Cumming's phenomenon distinguishes iron and steel from all other substances. The difference between iron and steel, finally, is exhibited in like degree by the maximum of permanent magnetization, by the maximum of permanent hardness (Strain), and probably by the maxima of other strains which these metals, under like conditions, respectively retain.

In the substance malleable cast-iron there is encountered a remarkable example of the occurrence of mechanical hardness unaccompanied by an equivalent variation of the electrical properties.

The existence of the characteristic strain in glass-hard steel is the cause of electrical effects so enormous that such additional effects which any change in carburation may involve can be wholly disregarded, and all electrical and magnetic results interpreted as due solely to variations in the intensity of the said strain.

*Chapter IV.*—Both the galvanic and the thermo-electric effects of magnetization are negligible in comparison with the corresponding electrical effects of tempering—the former amounting to less than 0.3 per cent. of the latter in the most unfavorable case.

The absolute value of the said thermo-electric effect for magnetically saturated iron is $+0.035$ microvolts per degree centigrade, at zero.

The thermo-electric effects of a temporary tensile strain in iron and of magnetization are qualitatively alike. Hence we infer that the latter effect is to be attributed to the strain which accompanies magnetism.

*Chapter V.*—Rigidly comparable data of the relation between magnetism and hardness are not readily obtainable except with magnets which were originally integrant parts of the same (hard) steel rod of uniform temper throughout its length. The plan of experimentation is expediently made to conform with a passage from hard to soft.

If magnetic moment (C. G. S.) per unit of mass ($g$) be regarded as a function of hardness, the family of curves obtained exhibits the following general character: Magnets, whether long or short, after incipient annealing from the glass-hard state diminish in magnetizability to a pronounced minimum of this quality. If the annealing be continued magnetizability again increases to an enormously developed maximum in case of rods of large dimension-ratio, to a flat or indistinct maximum in case of small dimension-ratio. On passing from long to short steel rods

the minimum is found to move in a direction from hard to soft, at very slow rates, thus remaining in the region of glass-hardness; the maximum, on the other hand, in a direction from soft to hard, at somewhat more rapid rates. The unique maximum of permanent magnetizability will probably be exhibited by a linear steel rod, annealed from glass-hardness as far as the physical state of maximum density. The value of the unique maximum is demonstrably much above 785 C. G. S. units of intensity, or 100 C. G. S. units of moment per gramme-mass. Continued diminution of the dimension-ratio finally, will probably bring the said minima and maxima into coincidence in such a way that permanent magnetizability decreases uniformly from hard to soft.

The family of magnetic curves must be separately investigated for each given diameter (structure) and each given degree of carburation. If magnetic moment per unit of mass be regarded as a function of the dimension-ratio ($\alpha =$ length / diameter), the family of curves obtained (conveniently described with the aid of the four type curves: "glass-hard," "yellow annealed," "blue annealed," "soft,") exhibit the following general character:

The curve "glass-hard" is concave as regards the axis of abscissæ (dimension-ratio) throughout. Rising very rapidly at first, it finally ascends to a distinct limiting value or horizontal asymptote. The curve "soft," on the other hand, rises very slowly in its earlier stages, and is convex as regards the axis of abscissæ. From here it passes rapidly through a point of circumflexion into concavity, and then above the former curve. Finally, the rate of ascent again decreases, so that a horizontal asymptote is also reached, but apparently at a later stage of progress than is the case with hard steel.

From either of these two loci expressing the variations of the extreme states, we may by annealing pass continuously to the other. But the manner of such passage, from the one curve to the other, in consequence of the continuous change of parameter (hardness), is exceedingly complicated. Incipient annealing of glass-hard steel produces a distinct, though relatively small, descent of the original curve as a whole. As annealing progresses, the farther end of the curve is always the first to rise and to pass above the original curve in such a way that the point of intersection of the new curve and the original curve (glass-hard) moves along the latter with great rapidity, from greater to smaller values of the dimension-ratio. When the curve "yellow annealed" is reached, the part of it between a small value of the dimension-ratio, $\alpha$ ($= 14$ and 18, in the above measurements, for diameters $2\rho = 0.08$ cm. and 0.15 cm.), and $\alpha = \infty$, has been already elevated above the curve "glass-hard." At the stage of progress given by the blue annealed curve, the part between another small value of $\alpha$ ($\alpha = 15$ and 20 in the above results) and $\alpha = \infty$ has risen far more rapidly than before, while, on the other hand, the advancing part of curve between $\alpha = 0$ and the said small value ($\alpha = 15$ or 20, respectively) having descended very grad-

ually, is now distinctly convex downward. Passing from "blue annealed" to "soft," the part of the curve above smaller dimension-ratios continues to fall, in general at greater rates, finally to merge into the curve "soft." The remaining part, above greater dimension-ratios, still rises slowly, reaching its superior elevation, from which it then falls rapidly into coincidence with the extreme curve "soft" also. During this last phase of progress the point of intersection of the advancing curve and the curve glass-hard passes along the latter from smaller to larger values of the dimension-ratio.

*Chapter VI.*—In considering the permanent magnetic effect of temperature on steel permanently saturated, it is necessary to discriminate sharply between two species of magnetic loss:

1. The direct effect, due simply to the action of temperature, and to be ascribed to diminution of coercive force and to interference of thermal expansion with the magnetic strain.

2. The indirect effect, due to the action of temperature in producing mechanical annealing, and to be ascribed to the interference of the rearrangement of molecules resulting, with the magnetic strain.

The two effects are frequently superimposed. Considered separately, the latter (indirect effect) is by far the greater in amount, and its character, with regard to magnitude and duration, fully typified by the concomitant phenomenon of ordinary mechanical annealing. The former (direct effect) is not only of smaller magnitude, but subsides completely within a very much smaller interval of time. A third (temporary) effect of temperature does not fall within the scope of the present work. If the contemporaneous effects of the action of temperature on permanently saturated glass-hard magnets, viz., reduction of magnetic moment per unit of mass (ordinates) and of specific resistance (abscissæ), be compared graphically, the loci of the relation pass from pronounced convexity, as regards the axis of abscissæ, almost horizontally through a point of circumflexion into pronounced concavity. It must be borne in mind that both the direct and indirect effcts are here superimposed. The said curves, if constructed for different dimension-ratios, are approximately parallel, presenting greater curvature, however, for smaller dimension-ratios than for larger. The immediate bearing of temper on the indirect effect is strikingly shown by the fact that, in the case of long, hard, permanently saturated steel rods, the relation between permanent magnetism per unit of mass and resistance, where both variations are simultaneous and due to changes of temper only, and where the latter occurs between the maximum of permanent hardness for ordinary temperature and the maximum of the same quality for 100°, is ultimately ($a = \infty$) linear.

The maximum of permanent magnetization for any given temperature, $t°$, which can be imparted to a steel rod exhibiting the maximum of permanent hardness for the same temperature, $t°$, is wholly independent of the possibly pre-existing states of magnetization. If $t = 100°$,

such magnets possess exceptional retentiveness both as regards effects of (atmospheric) temperature and time and of percussion.

The following rules for the practical treatment of magnets, where great retentiveness is the principal desideratum, we believe to be justified in submitting:

1. Rods tempered glass-hard are not to be used as essential parts of magnetic instruments.

2. Having tempered a given steel rod in such a way as insures uniformity of glass-hardness throughout its length, expose it for a long time (say 20–30 hours; in case of massive magnets even longer intervals of exposure are preferable) to the annealing effect of steam (100°). The operation may be interrupted as often as desirable. The magnet will then exhibit the maximum of permanent hardness for 100°.

3. Magnetize the rod—whether originally a magnet or not is quite immaterial—to saturation, and then expose it again for about 5 hours (in case of massive magnets even larger intervals of exposure are preferable) to the annealing effect of steam (100°). The operation may be interrupted as often as desirable. The magnet will then exhibit both the maximum of permanent magnetization as well as the maximum of permanent hardness corresponding to 100°. Its degree of magnetic retentiveness against effects of temperature ($< 100°$), time, and percussion is probably the highest conveniently attainable.

*Chapter VII.*—Given any iron-carburet, pure or impure.

Suppose carburation to vary continuously from 0 per cent. to 6 per cent. by weight of the whole, in any definite manner, and in such a way that increment in total carbon is compensated by decrement in total iron. Let there be no further change in the ingredients of the carburet. In this way we generate a special *series* of iron-carbides of which the given carburet is a particular member.

Such a series of iron-carburets exhibits the following characteristics:

If cooled from a temperature in red heat as rapidly as possible, thermo-electric hardness varies continuously with carburation, at a gradually retarded rate, and in such a way that the locus ascends rapidly during the earlier stages of progress, very slowly during the later stages. As a whole, therefore, the curve shows pronounced concavity downward.

If cooled from the same temperature in red heat with all desirable slowness, thermo-electric hardness varies continuously with carburation, at a gradually accelerated rate, and in such a way that the locus ascends slowly during the earlier stages of progress, very rapidly during the later. As a whole, therefore, the curve shows pronounced convexity downward.

The difference between the values of thermo-electric hardness for the same carburation passes through a maximum in the region of steel.

The difference between the logarithms of the respective values of thermo-electric hardness for the same carburation passes through a pro-

nounced maximum, defining a carbide, the mechanical properties of which are those of a type steel, and may be fully given thus:

Let each member of the whole series of iron-carburets be subjected successively to the following operations:

I. A process of very slow cooling from a given temperature in red heat.

II. A process of most rapid cooling possible from the same temperature.

If now the carburets be examined with reference to the hardness produced in the two instances, there will be found among them a certain unique member, whose properties are such that while process *I* has more nearly identified it with pure soft iron, process *II* will have moved it further away from this initial carburet than is simultaneously the case with any other iron-carbon product; a unique member, in other words, which is capable of occurring in the greatest number of states of hardness relative to the soft state, possible. To the said product the term "steel" is to be applied.

Similar deductions may be made from the critical values of specific resistance of iron-carburets.

The variation of a function like the one in hand in the neighborhood of a maximum is small. Hence a group of iron-carburets disposed on either side of the said maximum will possess properties sufficiently alike to be practically or commercially identical with the accurately defined type.

The general statement of the problem of which a special solution is contained in Chapter II is this:

The extreme values of thermo-electric hardness, *i. e.*, the values corresponding to sudden cooling and thorough annealing, respectively, describe any given member of any given series of iron-carburets with reference to its chemical properties. In other words, the said extreme values fix its position in a diagram of classification peculiar to iron-carburets. The intermediate values of thermo-electric hardness, *i. e.*, the values lying between the extremes and obtainable by annealing of the previously chilled carburet, describe the same product with reference to its mechanical properties. In other words, the said intermediate values determine its position in a scale of hardness peculiar to the particular iron-carburet in hand.

Given the same iron-carburet pure or impure, as before. To this belong another series of carburets, so generated that while chemical composition remains unchanged, the mode of occurrence of carbon passes from an initial extreme phase to a final extreme phase. In the simple case, where carbon is present in the combined and uncombined modifications only, $\frac{\text{combined } C}{\text{Total } C}=0$ may be regarded as the initial phase, $\frac{\text{combined } C}{\text{Total } C}=1$, as the final phase of occurrence. The character of the variation of thermo-electric hardness with the generating variable—con-

veniently termed qualitative carburation—cannot as yet be enunciated. The totality, or whole class of iron-carburets of which the given sample is a particular member, finally, may be expressed by a diagram in three dimensions, in which thermo-electric hardness appears as ordinate, quantitative carburation (total carbon in per cents.) as one independent variable, $x$, qualitative carburation as the other independent variable, $y$. In the general equation of such a surface, impurities (S. P. Si. Mn. etc.) including any further modification of carbon, are indicated by arbitrary constants (parameters). Any variation of each or all of these is equivalent to a passage from one definite classification-surface to another.

In constructing the diagram use was made of a class of easily measurable physical properties, thermo-electric hardness and specific resistance, which in the case of iron-carburets, from their simplicity and pronounced character, seem above all others to be adapted for purposes of discrimination and classification. In addition to these, however, both the density and magnetic quality (magnetic moment per unit of mass of permanently saturated *linear* rods) of iron-carburets are similarly, though less conveniently, available. On the basis of the above magnetic researches it may be safely affirmed that the given plan of discussion, if applied in turn to these functions, must lead to a classification-diagram differing in no essential respect from the above.

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# APPENDIX.

## ON THE RELATION BETWEEN THE THERMO-ELECTRIC PROPERTIES, THE SPECIFIC RESISTANCE, AND THE HARDNESS OF STEEL (1879).[175]

### 1.—INTRODUCTORY REMARKS.

The experiments which gave rise to the following paper were commenced with the view of further studying the relation between the maximum of permanent magnetism, hardness, and form of steel, a subject proposed for inaugural work by Professor Kohlrausch.

Although this question has elicited considerable experimentation ever since Coulomb's[176] time, it was not until comparatively recently that harmonious results were arrived at, chiefly through the labors of Ruths,[177] Rowland,[178] Gaugain,[179] Fromme,[180] Trève and Durassier,[181] and Gray.[182] All these observers, however, classified steel, with reference to its hardness, either simply into hard and soft, or accepted the colors of the oxide film on the tempered bar as a criterion of distinction sufficient for their purposes. It seemed, therefore, that the most probable method of further elucidating the magnetic subject referred to would consist in attempting to find some method by which the hardness of steel can be more distinctly and more rationally expressed. My endeavor was, in other words, to give the very vague notion hardness, as applied to steel, a *quantitative* signification. So long, however, as the ultimate nature of hardness does not admit of accurate definition, it is sufficient for the accomplishment of this end to examine some of the other properties of steel, which likewise vary with its hardness, and by considering the magnetic moment, *cæteris paribus*, as dependent on the former, to eliminate, as it were, the notion of hardness between them. My attempt is, in short, to find an expression of the more complicated functions of

[175] This is here printed for its bearing upon the discussion of steel, in the form of its original publication in the Phil. Mag. (5), VIII, pp. 341-368, 1879.

[176] Coulomb: Biot. Phys. III, p. 108, &c.; Hansteen: Pogg. Ann., III, p. 236, 1825; Müller: Pogg. Ann., LXXXV, p. 157, 1852; Plücker: Pogg. Ann., XCIV, p. 28, 1855; Wiedemann: Pogg. Ann., CVI, p. 169, 1859; Lamont: Handbuch. d. Magnet., pp. 223, 249-253.

[177] Ruths: Inaugural Dissertation, p. 34. Darmstadt, 1874.

[178] Rowland: Phil. Mag. (4), L, p. 361, 1875.

[179] Gaugain: Comptes rend., LXXXII, p. 145, 1876.

[180] Fromme: Gött. Nachr., No. 7, 1876, p. 157 *et seq.*

[181] Trève and Durassier: Ann. de Chim. et de Phys. (5), V, p. 266, 1875.

[182] Gray: Phil. Mag. (5), VI, pp. 321-3, 1878.

hardness, *cæteris paribus*, in terms of the more simple. Of the latter, the therme-electric properties and the specific resistance of steel, both admitting of accurate and easy determination, appear most suitable.

But the experiments on hardness and the electrical properties alluded to, although only introductory in their character, gave rise to a number of new results. I determined, therefore, to publish them separately. To obtain as complete a picture as possible of these phenomena I have made free use of all the information on the subject within my reach. In each case the author borrowed from is cited.

## 2.—APPARATUS FOR HARDENING THIN STEEL WIRE.

For reasons which become apparent below[183] the principal experiments of the following paper are confined to thin rods cut from the same coil. The rather difficult task of hardening these homogeneously throughout their length, without giving rise to a change in their chemical composition (either from oxidation or carburation), I believe to have accomplished by the aid of the following apparatus:

A glass tube 200 to 300 millimeters long, 8 millimeters wide, was provided at a distance of about 80 millimeters from one end, with two opposite apertures *aa*, Fig. 26, each about 3 millimeters in diameter. This part was then surrounded with a cork, *A*, perforated perpendicularly to the axis of the tube in a manner to correspond with the holes *aa*. This arrangement is fastened vertically in a suitable iron stand (not shown in the figure). The wire to be hardened is introduced into the tube and fastened below to a brass rod, *bh*, fitting tightly in the perforation *baab*, and above to the spring *dK*. For the purpose of fastening the lower end it was found sufficient, after having previously wound it around the rod *bh* so as to form a coil which could easily be made to slide off, to push the rod through *baab* and the coil, the latter having been introduced into the tube from the top. The spring *dK*, round the lower half of which the other end of the wire was wound, the upper half being provided with a clamp-screw *gg*, was fastened to a second arm of the stand (also omitted in the figure). By properly adjusting the rod *bh* and the arms of the stand the wire could be brought into coincidence with the axis of the tube and stretched as far as was necessary.

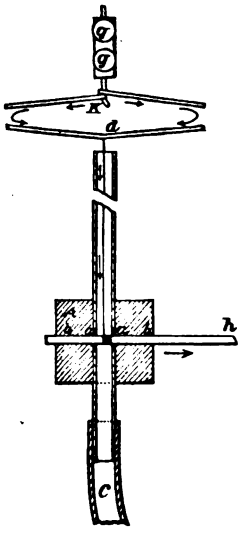


FIG. 26.—Apparatus for hardening.

[183] Difficulties due to structure, *vide* § 7, d.

A powerful galvanic current heated the wire to the degree of redness desired. The former entered *gg* and passed back to the battery through *bh* (as shown in the figure). To prevent the oxidation of the wire during the heating, a current of dry $CO_2$-gas,[184] was passed through the tube, entering by means of the hose *C* attached to the lower end.

After the wire had attained a steady uniform glow the hose *C* was closed by the fingers, its connection with the carbonic-acid apparatus disadjusted, the open end being connected with a neighboring hydrant instead; hereupon the faucet of the latter was quickly opened, the galvanic current being at the same time interrupted; the water dashing up the tube (as an unbroken column, however) with great velocity, imparts to the wire the hardness desired. Before each experiment the parts of the apparatus were well dried in a current of air.

The apparatus described presents the following advantages:

(1) By employing currents of different intensity, thus heating the wire to different degrees of redness, we are able to obtain corresponding degrees of hardness, which, though scarcely distinguishable mechanically (all appearing equally hard and brittle), have very different effects on the magnetic and electrical properties of steel.[185]

(2) From the fact that the wire is kept in a state of continual tension by the spring *dK*, and from the particular method of chilling, the wires remain straight after being hardened.

(3) The very slight oxidation noticeable on the hard wires is probably due to the contact of water and steel in the act of hardening.

Disadvantages, however, arise from the fact that the use of the apparatus is confined to thin bars, and that the wires obtained may be in a state of circular magnetization. This would partly prevent their employment in (certain) subsequent magnetic experiments. The difficulty may however be avoided by opening the galvanic current a little before opening the faucet.

## 3.—METHODS OF MEASURING THE HARDNESS OF STEEL ELECTRICALLY.

(*a*) *Thermoelectric position and hardness of steel.*—In this place it will be expedient to leave the special consideration of steel for the moment,

[184] Having accidentally employed moist carbonic-acid gas, a small flame was observed at the top of the tube. This is probably due to the combustion of $H_2$ and CO, the former being generated by the decomposition of aqueous vapor by the hot steel, the latter by the action of the nascent H produced on the $CO_2$.

[185] See IX. The coercive force of steel being a minimum at a point in incipient redness, it is possible that this apparatus might be used in obtaining intense circularly or longitudinally magnetic wires. In the first case, the wires should be cooled without breaking the current; in the second, the wires surrounded by a tube through which, during the act of hardening, a powerful galvanic current flows. (See Holtz, Wied. Ann., VII, p. 71, 1879.)

giving attention to the electromotive force of a thermo-element composed of any two different metals A′ and A″.

Kohlrausch[186] has shown that the phenomena included under the head of thermo-electricity can be explained on the hypothesis that the heat current is always accompanied by an electric current, whose intensity is proportional to the number of caloric units passing the same section. He thus arrives at an expression for the electromotive force between any two metals (A′ and A″) which, if for simplicity we suppose the cold end to be kept at zero,[187] has the following form:

$$E_\tau=[\vartheta'-\vartheta'']\ \tau\ [1+f(\tau)]$$

where $E\tau$ is the electromotive force corresponding to the difference of temperature, $\tau$, of the ends; $(\vartheta'-\vartheta'')$, a constant, specific for the combination.

This expression of Kohlrausch is very convenient, inasmuch as it allows us to separate the actual electromotive force into two terms, of which the first,

$$\vartheta'\tau\ [1+f(\tau)]$$

is dependent only on the metal A′ and $\tau$, the second, $\vartheta''\ \tau\ [1+f(\tau)]$, only on A″ and $\tau$.

Now, we know that the thermo-electric position of a metal is dependent not only on its chemical nature, but also on its mechanical condition (hardness). Let us therefore put

$$\vartheta'=\vartheta_0'+\theta' \qquad \vartheta''=\vartheta_0''+\theta''$$

where $\vartheta_0'$ and $\vartheta_0''$ are to represent the (absolute) constants dependent on the chemical nature of A′ and A″, respectively, $\theta'$ and $\theta''$, however, varying with the hardness of the metals. Thus the above equation becomes:

$$E_\tau=[\vartheta_0'-\vartheta_0'']+[\theta'-\theta'']\tau[1+f(\tau)]$$

But suppose that A′ and A″ are not different metals, but represent two rods to which different degrees of hardness have been imparted, which were originally, however, cut from the same wire. In this case $[\vartheta_0'-\vartheta_0'']=0$, whence

$$E_\tau=[\theta'-\theta'']\ \tau\ [1+f(\tau)]$$

dependent only on $\tau$ and the difference of hardness of the rods.

It will be shown below that the electromotive force of an element of soft and hard steel varies continuously with the difference of temperature $\tau$ and with the difference of hardness of the rods. We will therefore put $\theta''$, the constant belonging to the soft bar (*i.e.*, one which has been heated above redness and allowed to cool slowly in a badly conducting medium), equal to zero, as it is in this that the molecules will

[186] Kohlrausch: Pogg. Ann., CLVI, p. 601, 1875.

[187] The thermo-electromotive force being, according to Tait, Avenarius, Hankel, and others, a function of the temperature of the two ends.

most probably have assumed normal positions. If, furthermore, we replace $E_\tau = \theta' \tau\,[1+f(\tau)]$ by $E_\tau = a\tau + b\tau^2$, a sufficient approximation for practice, we derive $\frac{dE_\tau}{d\tau} = a + 2b\tau$ and $\left[\frac{dE_\tau}{d\tau}\right]_0 = a$, for $\tau = 0$.

This expression, *i. e.*, the limiting value of the electromotive force of a thermo-element composed of a soft rod and one of any degree of hardness to the corresponding difference of temperature[188] when the latter converges towards zero, will, in the sequel, be taken as the measure of hardness of the harder bar. I shall apply the term thermo-electric hardness abbreviated (T. E. H.) to it, throughout the following paper.

The relation between the thermo-electric properties and the hardness of steel, notwithstanding its comparative importance, has never to my knowledge been made the subject of detailed and exclusive study. All the experiments thus far published (the principal being those of Magnus,[189] Sir William Thomson,[190] and E. Becquerel[191]), are of a qualitative nature, the results being derived from the direction of the current observed on bringing together, in one way or another, wires of different hardness.

The experiments of Magnus, being limited to hard-drawn wires, do not properly fall within the scope of the present paper. The same is true of a number of the experiments in the excellent paper of Sir William Thomson. With regard to the effects of annealing Professor Thomson observes: "In cases of round steel wire, of steel wire flattened through its whole length by hammering, and of steel watch-spring, the thermo-electric effect of annealing portions after the whole had been suddenly cooled, was a current from unannealed to annealed through hot." This result comprehends all that has thus far been done.

(*b*) *Specific resistance and hardness of steel.*—With reference to the specific resistance and the hardness of steel, I shall proceed in a manner analogous to the preceding. Denoting the observed specific resistance of a bar by $S$, that part of $S$ which is due only to the chemical nature of the rod by $S_0$, that due to hardness by $\Delta S_0$, I have

$$S = S_0 + \Delta S_0$$

Now, as it follows from results given below that the specific resistance of steel increases continuously with its hardness, it will be convenient to put $\Delta S_0$ for the soft bar equal to zero. The value of $\Delta S_0$ for a bar of any degree of hardness, thus numerically determined, will in the following be accepted as a second measure of that property. The work thus far published on the relation between specific resistance and

[188] The colder end being supposed at 0°.

[189] Magnus: Pogg. Ann. LXXXIII, p. 486, 1851.

[190] Thomson: Phil. Trans., III, pp. 709–727, 1856.

[191] Becquerel: Ann. de Chim. et de Phys., (4), VIII, p. 402, 1866.

hardness of steel is due principally to Mousson.[192] Of late, results have been announced by Chwolson.[193] The data of both observers agree only qualitatively with mine, and among themselves.

## 4.—DETERMINATION OF THERMO-ELECTRIC HARDNESS. APPARATUS.

(*a*) *Method of measurement.*—In the determination of thermo-electric force the procedure known as Ohm's method was first employed. Afterwards it was found expedient to measure these forces (as Kohlrausch and Ammann[194] had done in similar experiments before) by a zero method, the object being to avoid the species of polarization due to Peltier's phenomenon. My method can easily be deduced from that proposed by Bosscha, the latter, in the case where small electromotive forces are to be measured, admitting of simplification. In the diagram, Fig. 27, $E$ denotes the compensating element (1 Daniell's element = 11.7 Weber × Siemens' units), $e$ the thermo-couple whose electromotive force is to be determined, both acting as shown in the figure, $C$ a Weber's commutator (employed for reasons given below), $G$ the galvanoscope. Let the resistance of the branch $ab$ be represented by $x$, that of the branch $aEb$ by $W+k$, where $W$ represents the large resistance of a rheostat interposed, $k$ that of the remainder of the branch (about equal to 1 Siemens' unit) including $E$. When the current in $G$ is zero we have,

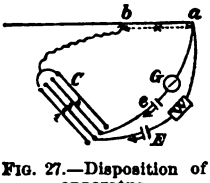

FIG. 27.—Disposition of apparatus.

$$\frac{e}{E}=\frac{x}{W+k+x}$$

But as $\frac{e}{E}$ is small, and therefore of necessity also $x$ (maximum value =10 S. U.), in comparison with $W+k+x$ (20,000 Siemens' units), I may with sufficient approximation, put

$$e=\frac{E}{W}x$$

the experimental accuracy attainable allowing me to neglect $(k+x)$ in comparison with $W$. In the experiments the branch $ab$ was a small Siemens' rheostat.

The precise moment at which the current in the galvanoscope is zero can be best determined by observing whether the needle on closing and opening the circuit remains at rest. This, however, is only possible when the opposed currents from $e$ and $E$ which pass through the galvanoscope are closed simultaneously. To accomplish this the little

[192] Mousson: N. Denksch. d. Schw. Gesellsch. (8), XIV, pp. 1–90, 1855.

[193] Chwolson: Mél. Phys. de St. Pétersbourg, X, p. 379, 1877. See also Carl's Repert., XIV, p. 15, 1878.

[194] Kohlrausch and Ammann: Pogg. Ann., CXLI, p. 450, 1870.

cups at the end of the rods 1 and 2 of the commutator were quite filled with mercury, those of 3 and 4 only partially. By this device, on closing, $C_1$ and $C_2$ are first brought into contact, and the current $EC_2\,C_1\,ba\,WE$, not passing through the galvanometer, comes into action; in the next moment ($C_3$ and $C_4$ being joined) the current from $e$ and the partial current from $E$ referred to are closed simultaneously. In this way also induction-currents which may possibly be generated in the rheostat, are without disturbing effect. The commutator merely serves the purpose of a double key.

As the electromotive forces to be measured were all very small, the large resistance $W$ could be left unaltered, so that $e = const.\ x$. Now, the resistance $x$ was so chosen that the intensity of the current from $e$ exceeded that of the partial current from $E$ by the minimum possible. The thermo-electric force, however, decreasing with the temperature, $T-t=\tau$ of the ends, a moment soon arrives at which the intensities of the two currents are equal, and the deflection of the needle $= 0$, in consequence. At this point the thermometers are read off.

(*b*) *Description of thermo-element.*—Instead of measuring the electromotive force of soft and hard steel directly, it was found expedient to compare all the rods with one and the same piece of copper wire. By this means the apparatus could be considerably simplified and many practical difficulties avoided. The construction of the copper-steel couple is given in vertical section in Fig. 28.

To raise the ends of the rod to different temperatures two doubly-tubulated receivers, each about 10 centimeters in diameter, were used. These, held in position by movable supports of poorly-conducting material, and so placed that the tubulures *A* and *B* were horizontal, the other two vertical, were connected by a glass rod *cd* fitting water-tight in the perforated corks adapted to the horizontal tubulures. This rod served a double purpose. By uniting the receivers as one it prevented breakage of the very brittle steel rods, at the same time allowing the receivers to be easily adjusted and removed; on the other hand the receivers could by means of it be placed at any distance apart, this being necessary, as the rods to be examined were of very different lengths.

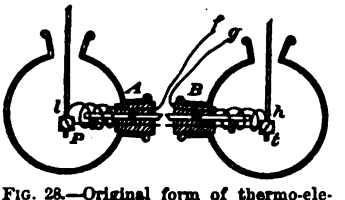

FIG. 28.—Original form of thermo-element.

On one side of the glass rod the copper wires which acted as poles of the instrument were inserted once for all; on the other two appropriate holes served for the introduction of the steel rods *ss* to be tested. The ends of the latter were connected with the corresponding ends of the copper wires by small flat clamp-screws of brass.

The apparatus being thus ready for experiment the two receivers were filled with distilled water at $T°$ and $t°$, respectively, where $t$ was so chosen as to differ but slightly from the temperature of the room.

The thermometers (introduced through the vertical tubulures) were read off with a telescope as follows: The deflection of the needle having become very small, $t$ was determined, after which, when the current in $G = 0$, $T$, whereupon another check-reading of $t$ was made. Before each observation the water in the receivers was well stirred.

(*c*.) *Galvanoscope.*—The galvanoscope used was a very delicate instrument of Sauerwald's, provided with mirror and astatic needle. The deflection of the latter was read off with telescope and scale. As the telescope of this instrument stood side by side with the telescope for the thermometers, both readings could conveniently be made by the same observer.

## 5.—DETERMINATION OF SPECIFIC RESISTANCE.

For determining the specific resistance of steel rods use was made of Wheatstone-Kirchhoff's bridge. An appropriate commutator allowed the observer to exchange the unknown resistances without altering the value of those belonging to the bridge proper. Thermo-electric disturbances were avoided as far as possible by closing the current (1 Smee with large resistance) only for very short intervals of time. Finally they were eliminated completely by replacing the hydro-electromotive force by Weber's magneto-inductor.[195] The resistances of all rods were determined in terms of an arbitrary standard $\delta$ (0.0312 Siemens unit at 0°), chosen to correspond in magnitude with the unknown resistances. The galvanometer used was the one already mentioned above.

As the resistances to be measured were all very small (0.1 to 0.01 Siemens unit), great care had to be taken to exclude all disturbing resistances due to insufficient contact. Soldering could not be resorted to, as it was believed that the ends would thereby be annealed. The method adopted was as follows: The ends of the rods having been well cleansed were covered to about 1 centimeter with a thin adhesive film of galvanically deposited copper, which was thereupon amalgamated (easily accomplished by plunging the freshly-covered part in mercury). The rod thus prepared was then fixed together with a glass rod in two corks, in a manner similar to that employed in the case of the thermo-element, and the whole, except the amalgamated ends, covered with a thick coat of varnish. Suitable wooden cups, provided with horizontal and vertical apertures, completed the connection of the rods with the respective parts of the bridge by means of mercury.

The efficient length was determined by deducting from the total length that of the amalgamated ends. For the measurement of diameter use

[195] Weber: Pogg. Ann., CXLII, p. 418, 1871. The use of the magneto-inductor in connection with the bridge was suggested by Kohlrausch. This physicist also showed that the method is applicable even when the resistances to be determined are in form of coils, the extra currents produced being calculable. I found the application of great convenience, inasmuch as the observer always has the needle of a delicate galvanometer completely under his control.

was made of the microscope. A determination of this dimension from known weight, specific gravity, and length was impracticable, inasmuch as the use of the pycnometer, which alone would have given sufficiently accurate results, would have compelled me to break the rods.

## 6.—EXPERIMENTAL RESULTS.

*A. Thermo-electric hardness of rods suddenly immersed in cold water while in different states of red heat.*—The following (older) results were obtained directly by Ohm's method. $E_\tau$ was put = constant $\tau$, a condition nearly fulfilled by couples of soft and hard steel between zero and 80°, in which case T. E. H. and the constant of proportionality are identical. The rods were hardened in the apparatus described in § 2; diameter = 0.0678 cm.; the numbers preceded by the point (.) were afterwards checked by the method of compensation. T. E. H. is expressed in Weber × Siemens units.

The third column of the following table contains the number of large Bunsen cells employed in heating the wire, the fourth the observed degree of redness at the time of sudden cooling.

TABLE I.

| No. | T. E. H. | Bunsen elements. | Remarks. |
|---|---|---|---|
| 1 | 0.0000004 | ..... | Soft, cooled slowly from red heat. |
| .2 | 0.000003 | 4 | Below redness. |
| 3 | 0.000012 | 5 | |
| 4 | 0.000000 | 5 | |
| .5 | 0.000000 | 6 | |
| 6 | 0.000000 | 6 | Ignited dark red. |
| 7 | 0.000052 | 7 | |
| .8 | 0.000049 | 7 | |
| 9 | 0.000054 | 7 | |
| .10 | 0.000056 | 8 | |
| 11 | 0.000057 | 8 | |
| 12 | 0.000063 | 8 | |
| .13 | 0.000064 | 9 | Ignited brick red. |
| 14 | 0.000065 | 9 | |
| 15 | 0.000064 | 9 | |

The Bunsen cups were introduced without altering the remaining part of the circuit. The length of the wire heated was not in all cases the same.

*B. Further thermo-electric data. Hard steel.*—The following determinations were made in the summer of 1878; temperature of the room very constant and at about 20°, this, as already observed, being nearly the same as $t$, the temperature of the water in the colder receiver. The method of compensation was employed throughout. The determination of $T$ was effected by a Geissler normal thermometer (graduated in 0°.1), that of $t$ by an ordinary instrument (graduated in 0°.2) which had, however, been carefully compared with the former.

In Tables II and III the difference of temperature of the ends of the steel rod is given under $\tau$, the corresponding electromotive force for the elements copper-steel under $E_\tau$; $\alpha$ and $\beta$ are constants which satisfy

the equation $E_\tau = a\tau - \beta\tau^2$. These were calculated by first computing their approximate values out of two distant observations, and then adding to them corrections deduced from five of the most satisfactory observations, by the method of least squares.

If, now, we denote by $a$ and $b$ the constants of an element soft-steel and hard-steel, corresponding to those $\alpha$, $\beta$, $\alpha'$, $\beta'$ of the same rods, when compared with copper, we shall have, since $E_\tau = a\tau - \beta\tau^2$ and $E'_\tau = a'\tau - \beta'\tau^2$,

$$E_\tau - E_\tau' = (a - \alpha)\tau - (\beta - \beta')\tau^2$$

But $E_\tau - E_\tau' = E_\tau$, the electromotive force of the element steel-steel; so that, since also $E_\tau = a\tau - b\tau^2$,

$$a = a - a^1 \qquad b = \beta - \beta^1$$

The constants $a$ and $b$ are given in the last two columns. $a$ may be regarded as numerically equal to the T. E. H. above defined, as $E_\tau$ is nearly a linear function of $\tau$.

TABLE II.—*Rods 0.0678 centimeters thick.*

| No. | $\tau$ | $E_\tau$ Observed. | $E_\tau$ Calculated. | $\alpha$ | $\beta$ | $a$=T. E. H. | $b$ |
|---|---|---|---|---|---|---|---|
| [1]I | 13.92 | 0.001464 | 0.001457 | 0.0001071 | 0.0000001733 | Nil ..... | Nil. |
| | 25.68 | 2635 | 2636 | | | | |
| | 39.78 | 3981 | 3985 | | | | |
| | 49.34 | 4859 | 4862 | | | | |
| | 62.65 | 6031 | 6030 | | | | |
| [2]II | 17.90 | 0.001815 | 0.001807 | 0.0001038 | 0.0000001629 | 0.0000031 | 0.0000000104 |
| | 31.39 | 3104 | 3100 | | | | |
| | 47.58 | 4567 | 4572 | | | | |
| | 56.53 | 5828 | 5849 | | | | |
| | 63.72 | 5972 | 5956 | | | | |
| [3]IV | 20.25 | 0.001112 | 0.001095 | 0.00005811 | 0.0000002006 | 0.0000490 | —0.0000000273 |
| | 29.20 | 1523 | 1526 | | | | |
| | 46.50 | 2283 | 2268 | | | | |
| | 59.90 | 2752 | 2761 | | | | |
| | 61.35 | 2810 | 2810 | | | | |
| [4]V | 18.07 | 0.000878 | 0.000881 | 0.00005156 | 0.0000001568 | 0.0000555 | 0.0000000165 |
| | 21.93 | 1054 | 1056 | | | | |
| | 47.76 | 2108 | 2105 | | | | |
| | 61.32 | 2576 | 2571 | | | | |
| | 63.44 | 2635 | 2640 | | | | |
| [5]VI | 15.75 | 0.000703 | 0.000700 | 0.00004660 | 0.0000001390 | 0.0000605 | 0.0000000343 |
| | 31.84 | 1347 | 1343 | | | | |
| | 43.51 | 1756 | 1765 | | | | |
| | 45.06 | 1815 | 1818 | | | | |
| | 59.42 | 2283 | 2278 | | | | |
| [6]VII | 19.04 | 0.000761 | 0.000764 | 0.00003807 | 0.0000001529 | 0.0000641 | 0.0000000294 |
| | 34.08 | 1288 | 1288 | | | | |
| | 53.64 | 1874 | 1867 | | | | |
| | 63.40 | 2108 | 2112 | | | | |
| | 68.30 | 2225 | 2225 | | | | |
| [7]VIII | 18.42 | 0.000644 | 0.000658 | 0.00003807 | 0.0000001279 | 0.0000690 | 0.0000000454 |
| | 31.15 | 1054 | 1062 | | | | |
| | 45.00 | 1464 | 1454 | | | | |
| | 62.10 | 1874 | 1871 | | | | |
| | 65.40 | 1932 | 1943 | | | | |
| [8]IX* | ..... | ..... | ..... | ..... | ..... | 0.0007?0 | ..... |

[1] Heated above redness and allowed slowly to cool in wood ash; "soft."
[2] Heated galvanically below redness, then suddenly cooled; "soft."
[3] Heated to dark redness, then suddenly cooled; "glass-hard."
[4] Heated to redness, then suddenly cooled; "glass-hard."
[5] Heated galvanically to brick-redness, then suddenly cooled; "glass-hard."
[6] Heated galvanically to brick-redness, then suddenly cooled; "glass-hard."
[7] Heated to yellow-ignition, then suddenly cooled; "glass-hard."
[8] Heated to yellow-ignition, then suddenly cooled; "glass-hard."
* This determination was made at a later date; with reference to its accuracy the remarks under *C* and *D* apply.

TABLE III.—*Rods 2.65 millimeters thick, tempered by Mr. Barth, mechanician.*

| No. | $\tau$ | $E_\tau$ Observed. | $E_\tau$ Calculated. | $a$ | $\beta$ | $a=T.E.H.$ | $b$ |
|---|---|---|---|---|---|---|---|
| [1]*D* | 32.28 | 0.002928 | 0.002918 | 0.00009447 | 0.0000001257 | 0.00001263 | 0.0000000476 |
| | 45.55 | 4040 | 4042 | | | | |
| | 46.88 | 4157 | 4153 | | | | |
| | 55.54 | 4860 | 4859 | | | | |
| | 56.24 | 4918 | 4915 | | | | |
| [2]*C* | 20.32 | 0.001639 | 0.001628 | 0.00008265 | 0.0000001229 | 0.00002445 | 0.0000000504 |
| | 31.98 | 2518 | 2517 | | | | |
| | 32.90 | 2576 | 2586 | | | | |
| | 47.93 | 3689 | 3678 | | | | |
| | 49.80 | 3806 | 3811 | | | | |
| [3]*B* | 32.40 | 0.001991 | 0.002004 | 0.0000646 | 0.0000000864 | 0.0000424 | 0.0000000869 |
| | 33.08 | 2049 | 2044 | | | | |
| | 50.47 | 3045 | 3043 | | | | |
| | 61.00 | 3630 | 3623 | | | | |
| | 62.25 | 3689 | 3690 | | | | |
| [4]*A* | 10.86 | 0.000117 | 0.000121 | 0.00000999 | 0.0000001068 | 0.00011710 | 0.0000000665 |
| | 27.20 | 351 | 351 | | | | |
| | 43.75 | 644 | 642 | | | | |
| | 58.12 | 937 | 942 | | | | |
| | 60.37 | 995 | 993 | | | | |

[1] Soft; gently ignited, slowly cooled.
[2] Tempered blue.
[3] Tempered dark yellow.
[4] Glass-hard.
* This rod (as also those of the following section *C*) is electronegative with reference to copper.

*B'. Specific resistance of the same material.*—The following Tables IV and V contain the specific resistances of the rods already cited in Tables II and III. The data are given in terms of mercury. The column $S$ contains the total specific resistances, $\Delta S_0$ the corresponding excess of the latter over that of the normal rod I. Of the ratio $\frac{\Delta S}{T.E.H.}$ mention will be made hereafter.

Let the resistances of the two parts of the first branch of the bridge, on each side of the sliding contact, be denoted by $a$ and $b$; let the resistances of the corresponding parts (thick copper wire) of the second branch of the bridge be denoted by $K'$ and $K''$. Into the latter the unknown resistances $W$ and $R$ are to be inserted, respectively. Finally, let $\delta$ be the standard of comparison above referred to, in terms of which $W$ and $R$ are to be measured. When the current in the galvanometer is zero, we shall have for a particular position of the commutator:

(1) $W$ and $R$ alone—

$$\frac{a}{b}=\frac{W+K'}{R+K''}$$

(2) $W$ and $R$ with $\delta$ on the right—

$$\frac{a'}{b'}=\frac{W+K'}{R+K''+\delta}$$

(3) $W$ and $R$ with $\delta$ on the left—

$$\frac{a''}{b''}=\frac{W+K+\delta}{R+K''}$$

Three similar equations may also be derived from the other position of

$$\frac{\delta}{\delta} \top \frac{a'}{b'} \bot \frac{a}{b} \qquad \frac{\delta}{\delta} \top \frac{b''}{a''} \bot \frac{b}{a}$$

$\frac{K'}{\delta}$ and $\frac{K''}{\delta}$ were determined in the same way previous to the ex

ments, and their values checked from time to time. In comparing resistances $I \ldots IX$ and $A \ldots D$, the following plan was observed

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $W:\delta$ | I | IV | IV | ..... | VIII | VIII | I | And in the same way with $A$ to $D$. |
| $R:\delta$ | II | II | V | ..... | VII | IX | IX | |

Each of the data is therefore derived as a mean of four determ tions. Possible heterogeneity of the wire $a+b$ thus becomes effective.

As an example, I will add results obtained for the rod $C$ (resis 0.0051 Siemens units):

| | | Compared with $A$. | Compared with $B$. | Compared with $D$. |
|---|---|---|---|---|
| 1st position..... | $W:\delta=$ | 0.1648 | 0.1654 | 0.1649 |
| 2d position..... | $W:\delta=$ | 0.1630 | 0.1632 | 0.1639 |
| | Mean.. | 0.1639 | 0.1643 | 0.1644 |

For the rod I (resistance=0.0542 Siemens units) on different occasi 1.735 and 1.741 were found for $W:\delta$.

As will be seen, the principal stress was put on relative values of resistances. To facilitate orientation, however, the results were proximately reduced to Siemens units by determining the standar in that denomination.

Assuming the coefficient for temperature for steel to be the sam

TABLE IV.

| No. | Resistance. | $S$ | $\Delta S_0$ | $\frac{\Delta S_0}{T.E.H.}$ |
|---|---|---|---|---|
| I.. | 0.05417 | 0.1361 | Nil. | ..... |
| II.. | 0.04305 | 0.1400 | 0.0039 | 1260 |
| *IV[1]. | 0.11130 | 0.2337 | 0.0976 | 1990 |
| V.. | 0.11060 | 0.2483 | 0.1122 | 2020 |
| VI.. | 0.07846 | 0.2592 | 0.1231 | 2030 |
| VII.. | 0.08740 | 0.2648 | 0.1287 | 2010 |
| VIII.. | 0.15330 | 0.2779 | 0.1418 | 2050 |
| *IX.. | 0.09417 | 0.2810 | 0.1449 | 2070 |

[1]The resistances marked with an asterisk were determined by using the magneto-inductor as a current generator. In the others a Smee element was employed.

TABLE V.

| No. | Resistance. | $S$ | $\Delta S_0$ | $\frac{\Delta S_0}{T.E.H.}$ |
|---|---|---|---|---|
| *D* | 0.00209 | 0.1654 | 0.0293 | 2320 |
| *C* | 0.00512 | 0.2065 | 0.0704 | 2860 |
| *B* | 0.00595 | 0.2271 | 0.0910 | 2150 |
| *A* | 0.00908 | 0.3804 | 0.2443 | 2090 |

The experiments now following, under the heads *C* and *D*, have more a descriptive character than one of precise measurement; the results are therefore given with one decimal less. For the determination of T. E. H. the rods coming under these heads were compared indirectly with rod VIII (Table II) for the T. E. H., of which the number 0.000069 (as above found) was assumed.

*C.* T. E. H., *and* $\Delta S_0$ *for glass-hard rods, diameter*$=2.30$ *millimeters.*— These were hardened by the aid of the blast lamp. The flame of the latter was for this purpose directed horizontally and placed directly over a trough containing cold water. In this way the red-hot rod could be transferred with great rapidity out of the flame into the water.

TABLE VI.

| No. | *T. E. H.* | Resistance. | $S$ | $\Delta S_0$ | $\frac{\Delta S_0}{T.E.H.}$ | Remarks. |
|---|---|---|---|---|---|---|
| *[I] | 0.000138 | 0.0121 | 0.421 | 0.285 | 2100 | Ignited yellow and chilled. |
| *[II] | 131 | ..... | ..... | ..... | ..... | Do. |
| *[III] | 130 | ..... | ..... | ..... | ..... | Do. |
| *[IV] | 130 | 0.0129 | 0.442 | 0.306 | 2300 | Do. |
| *[V] | 116 | 107 | 0.336 | 0.230 | 2000 | Ignited red and chilled. |
| *[V]' | 136 | 123 | 0.430 | 0.294 | 2200 | [III] u. [V] Twice re-ignited yellow and chilled. |
| *[III]' | 133 | ..... | ..... | ..... | ..... | |

*D.* T. E. H. and $\Delta S_0$, of rods 0.678 millimeter in diameter, hardened[196] in the apparatus §2, afterwards *annealed* by immersion in hot linseed oil.

[196]The T. E. H. of these rods in the glass-hard condition varied from $50:10^6$ to $60:10^6$.

TABLE VII.

| No. | *T. E. H.* | Resistance. | *S* | Δ *S*e | $\frac{\Delta S_e}{T.E.H.}$ | Remarks. |
|---|---|---|---|---|---|---|
| *1 | 0.000010 | 0.0540 | 0.157 | 0.021 | 2100 | Glass-hard and gradually heated to 300° in linseed oil.[1] |
| *2 | 13 | 0616 | 158 | 022 | 1700 | |
| *3 | 11 | 0537 | 159 | 023 | 2100 | |
| *4 | 14 | 0691 | 163 | 027 | 1900 | |
| *5 | 12 | 0592 | 166 | 030 | 2500 | |
| *6 | 18 | 0763 | 177 | 041 | 2300 | Similarly annealed at 280°. |
| *7 | 24 | 0659 | 185 | 049 | 2000 | Similarly annealed at 240°. |
| *8 | 33 | 0746 | 205 | 069 | 2100 | |
| *9 | 31 | 0807 | 206 | 070 | 2200 | Similarly annealed at 200°. |
| *10 | 36 | 0731 | 209 | 073 | 2000 | |
| *11 | 57 | 0.1088 | 250 | 114 | 2000 | Similarly annealed at 150°. |
| *12 | 58 | 0.1155 | 261 | 125 | 2200 | |
| Soft iron. | −0.000004 | 0.0426 | 0.133 | −0.003 | 750 | Heated to redness in Bunsen's blast-lamp and slowly cooled. |

[1] Rods 1 to 5 remained in the bath during the whole process; the others were immersed but for 2m to 3m. The temperature at which the rods 6 and 7 were annealed could not be determined with certainty, a microscopic air-bubble in the neck of the mercury reservoir having given rise to rupture of the thread.

*E. Corroborative measurements.*—The resistances thus far determined being very small, it was feared that in spite of the continuity apparent in their variation, errors from insufficient contact might have conspired in producing illusory results. For these reasons check-experiments with longer wires were made, the resistance of some of which (I to V) is sufficiently great to admit of direct comparison with the Siemens mercury unit (étalon). To insure a more homogeneous hardening, these wires were spirally wrapped around a round stick of wood, and the length and diameter of the coils resulting so determined that the whole during the process of heating could be brought within the mantle of the blast-flame. In other respects the method given under *C* was pursued.

TABLE VIII.

| No. | Resistance. | Length. | Diameter. | *S* | Δ *S*e | Remarks. |
|---|---|---|---|---|---|---|
| I | 0.643 | 0.880m | 0.67 | 0.260 | 0.124 | Ignited yellow; then suddenly cooled. |
| II | 379 | 917 | 96 | 296 | 160 | Do. |
| III | 245 | 928 | 1.19 | 293 | 157 | Do. |
| IV | 121 | 932 | 1.83 | 342 | 206 | Ignited red; then suddenly cooled. |
| V | 105 | 556 | 1.62 | 391 | 255 | Ignited light yellow; then suddenly cooled. |
| *VI | 0169 | 733 | 2.15 | 354 | 218 | Ignited red-yellow; then suddenly cooled. |
| *VII | 0155 | 732 | 2.15 | 325 | 189 | Ignited red-yellow; but ends darker. |
| *VIII | 0169 | 740 | 2.15 | 352 | 216 | Ignited red-yellow; then suddenly cooled. |

Spirals II and IV were afterwards softened by heating to redness in a Bunsen burner. Their specific resistance in this condition was found to be

*II. $S_0$=0.154 *IV. $S_0$=0.159

Finally, in order to compare the results obtained with induction currents with those in which a Smee element was employed, certain of the experiments were repeated. The agreement was entirely satisfactory.

## 7.—HARDNESS AND THERMO-ELECTRIC PROPERTIES OF STEEL: DEDUCTIONS AND SUPPLEMENTARY EXPERIMENTS.

(*a*) *Thermo-electric and mechanical hardness.*—From the data contained in Tables II, III, and VII, we derive that the thermo-electric position of steel progresses continuously with its degree of hardness, or, in other words, thermo-electric and mechanical hardness are direct functions one of another.

This statement involves the assumption that the rod cannot pass from the glass-hard (maximum) to the soft state (minimum) without passing through every intermediate stage; or that by proper methods of annealing, every state between the maximum and minimum can be produced. This, I dare say, will generally be admitted.

As of further interest I may add: (1) that rods cut from the same wire and glass-hardened in the same way possess also the same thermo-electric hardness (Table VI); (2) this is the case even when the rods are carefully rehardened (rods [III]′, [V]′, Table VI); (3) that if we start from like maxima, the thermo-current always passes from less to more annealed, through warm. (The direction of the current was independently observed.)

(*b*) *Variation of T. E. H. with differences of material and of thickness.*—From an examination of the data obtained for different material, we infer that the T. E. H. of soft and similarly annealed rods approximates to the same value;[197] that the value of this constant for glass-hard rods is remarkably different. The rods in Table VI, for instance, possess a T. E. H. amounting nearly to $140 : 10^6$; whereas in the rods in Table II the maximum[198] value found does not exceed $70 : 10^6$. This may be due to a difference in thickness, or, more probably, to a difference in the composition of the rods examined.

These phenomena were further studied through the following experiments:

1. Commercial rods of different diameters were glass-hardened and examined with reference to the current produced when one end of a couple was cooled with a wedge-shaped piece of ice. In general a maximum of T. E. H. was observed in rods whose diameters lay between 1 and 2 millimeters. These experiments, however, are unsatisfactory, inasmuch as the composition of the rods enters as an element of dis-

[197] In order to compare the degree of hardness corresponding to a particular oxide tint with that corresponding to a given temperature of the oil bath, use was made of the tables found in Frick's Physikal. Technik, 3 ed., p. 377; also Wagner, Chem. Tech., 8 ed., p. 29. On the authority of these works 230° corresponds to yellow, 290° to blue, annealed. We should therefore expect rods 6, 7, and 8, 9 (Table VII) to agree with the rods *C* and *B* (Table III) respectively. This is sufficiently the case.

[198] These rods (Table II), even when heated to the utmost white and suddenly cooled, remained strongly electro-positive towards copper. T. E. H., even in this extreme case, was much less than $107 = 10^6$.

turbance which cannot be allowed for. For this reason experiment were made on thick bars, the parts of which had been filed to differen diameters.

2. The halves of each of two pieces cut from the same rod, 5 millime ters in diameter, were reduced[199] by filing to thicknesses of 3 millimeter and 1 millimeter, respectively, and glass-hardened. During the proc ess of heating care was taken to raise all parts of the bars to the sam degree of redness. On connecting the ends with the galvanometer an applying the ice wedge at the middle (where the diameter enlarged) very decided currents were observed, passing from thin to thick through warm. Hereupon two cones were filed of the same material (5 milli meters thick at base and 50 millimeters long). Point and base of the cones (previously glass-hardened) being connected with the galvano scope, the ice wedge applied at any point produced in each case currents from apex to base through warm, thus harmonizing with the previous experiments. Near the points only the results became uncertain. On bringing together the cones with the rod [IV] (Table VI) the points were found to be thermo-electrically harder, the base softer than the rod. On the other hand, the point of a fine needle prepared from the same material gave contrary indications. The point, therefore, was apparently softer than rod IV.

3. Finally two very gradually tapering cones were prepared from another steel rod, 2.8 millimeters in diameter. Connection with the galvanometer being made, the application of the ice wedge to parts near the base generated a current from thin to thick through warm; to parts near the apex, a current in the opposite direction. Finally, be- tween these a position was found at which the application of the ice wedge produced no current at all. This occurred at parts about .5 millimeters in diameter. The other cone gave like results.

4. When the bases of two similar cones of the same materials are connected with the galvanometer and their apices brought in contact, upon warming the latter, a current in one direction or another will be produced; this from the fact that the points are rarely equally hard. Experiment shows that by consecutively warming parts which lie sym- metrically to the right and left of the apices in contact, currents in op- posite directions are the effect. Herefrom it follows that the currents originate each in a single cone.[200]

5. In endeavoring to generalize from these experiments, attention must be paid to the following points: *a*, the maximum value of T. E. H. attainable is dependent on the quantity of carbon contained in the steel. The thermo-electric difference between rods of soft and sud-

[199] It is to be observed that the thinner parts of these pieces sooner arrive at red heat and remain longer in this condition than the thicker parts. This applies equally to the cones.

[200] The experiments with two separate cones were equally successful when the con- ical forms were only part of the same continuous piece.

denly cooled wrought iron can, for instance, be neglected in comparison with the corresponding difference between hard and soft steel. *b*, T. E. H. is influenced by the temperature of the rod when suddenly chilled (VII *c*), as well as by the time of heating, the latter affecting the composition. *c*, By the form of the piece of steel and the method of sudden cooling, the internal structure of the mass being thereby modified (VII *d*). *d*, Finally, we might add that, in the time elapsing between the removal of the rod out of the fire and the subsequent immersion, the loss of heat by radiation will be relatively greater in the case of thin than in the case of thick rods.[201] With these facts in mind we may conclude that the maximum values of T. E. H. attainable by glasshardening rods of the same composition increases as thickness diminishes; that as this dimension continues to decrease a diameter is reached at which the negative effects of decarburization are equal and finally overcome by the positive effects due to diminution of diameter.

(*c*) *Effect of the temperature from which steel is suddenly cooled in hardness. Chemical and mechanical hardness.*—From the results contained in Table I there follows: The hardness of steel does not increase continuously with its temperature at the moment of sudden cooling, but at a point in dark red heat the glass-hard state is suddenly attained. From this point on, however, the degree of glasshardness (measured electrically) continues to increase with the temperature. This observation conduces to the conclusion that the change of state due to glass-hardening is chemical in its nature. In this opinion, I believe, most chemists at present also concur, it being assumed that the uncombined carbon in soft steel is, by sudden immersion, converted into the chemically combined. In summing up the facts by which the hypothesis is furthermore supported, I will mention in the first place the detailed analogy[202] which exists between the white pig (used in the manufacture of Bessemer steel) and glass-hard steel, on the one hand, and ordinary (gray) cast-iron and soft steel on the other; the former containing carbon only in the combined, the latter also in considerable proportion in the uncombined, state. Secondly, hardening by a process of wire-pulling, hammering, etc., will, in all probability increase the specific gravity of steel; hardening by sudden cooling, as is well known, di-

[201] I will add here (1884) that another possible source of error was overlooked in the above. I refer to the electro-motive force of superficial layers in case of loose contracts, as investigated by Franz (Pogg. Ann., LXXXV, p. 388, 1852), Jenkin (Rep. Br. Assoc., 1861, (2), p. 34), Gaugain (C. R., XXXVI, p. 612–16, 1853, Ann. de Chim. et de Phys. (3). LXV, p. 75–102, 1862) and others. But I feel confident that these phenomena are not contained in the above: 1, because loose contacts were avoided; 2, the metals were always bright and polished; 3, the results were the same when difference in diameter (double cone) occurred in one and the same continuous piece of steel; 4, from the variety of experiments made and the uniformity of the results obtained.

[202] See Wagner: Chem. Tech., 8 ed., pp. 14, 15, 29. These analogies refer to mechanical properties, method of preparation, color.

minishes it. In the former case the thermo-electric current usually passes from soft to hard through warm;[203] in the latter, in the contrary direction. In drawn wire the specific resistance is smaller,[204] in hard tempered greater than that of the same wire in the soft state.

Considering these facts as a whole, we are perhaps justified in distinguishing between a process of chemical and a process of mechanical hardening. This, however, does not prevent us from paying due regard to a series of physical phenomena which accompany the former. To these the peculiar internal structure of glass-hard bars, the warping which frequently attends sudden cooling, etc., are to be referred. We conclude, therefore, that the cause chiefly influential in bringing about glasshardness in steel is chemical in its nature, and that, in consequence of the physical phenomena which invariably accompany it, the degree of glasshardness is more or less modified. On the latter ground the continual increase of the T. E. H. after the critical temperature above referred to has been reached is to be explained.

(*d*) The observed T. E. H. can, of course, only be assumed as directly expressive of its hardness when the rod under experiment is homogeneous throughout. In thick bars, which in the glass-hard state may be considered as made up of a series of concentric cylindrical shells, the hardness of which decreases rapidly as we pass from the exterior to the interior, the circumstances become more complicated.

Furthermore, suppose the ends of a thick glass-hard cylinder to be kept at temperatures $T$ and $t$ ($T>t$). In this case, since each of the infinitely thin cylindrical shells has a particular T. E. H. corresponding to its hardness, we are led to infer that thermo-currents, closing themselves in the interior of the cylinder, are the result—the direction of these in the outer harder parts being from $t$ to $T$, in the inner from $T$ to $t$. In figure 29 (vertical section) the hypothetical condition of the cylinder in this case is indicated. As will be seen, its electrical state corresponds to that of a rod circularly magnetized.

Fig. 29.—Thermo-currents evolved in a hard thick cylinder.

For the purpose of studying this question experimentally, a steel cylinder, 30 millimeters in diameter and 50 millimeters long, was turned and glass-hardened. This was placed vertically directly before the needle of a magnetometer (the deflection of which could be read off with telescope and scale) in such a manner that the position of equilibrium of the needle was left unaltered. The relative position of the needle and cylinder, in other words, was such that the axis of the former, if prolonged, would intersect the axis of the latter if prolonged at its middle point. Upon now cooling the

[203] Magnus: Pogg. Ann., LXXXIII, p. 469, 1851; Sir W. Thomson, Phil. Trans., III, p. 722, 1856.

[204] Mousson: N. Denkschr. d. Schwz. Gesell., XIV, 8, p. 1–90; Chwolson: Carl's Rep., XIV, p. 15.

upper end of the cylinder with a piece of ice, or warming by projecting a jet of steam against it, very decided deflections were observed toward the right or left, respectively, which increased with the difference of temperature $T-t$, and vanished as this difference became nil.

As the cylinder was not magnetic, it is improbable that these phenomena can be referred to a change in the state of magnetic distribution. With reference to the direction of the currents, however, no simple results could be arrived at.

(*e*). *Relative thermo-electric qualities of soft steel and soft iron.*—In § 7, *c*, we ascribed the very high value of the T. E. H. of a glass-hard steel rod to the large proportion of chemically combined carbon contained therein. If this be true, the thermo-electric difference between soft steel and soft iron, in both of which combined carbon is either wholly absent or exists only in traces, must be quite small. This inference is supported by the data actually found for soft iron. Making allowance for the difference of circumstances involved, the result to be derived from the experiments of Kohlrausch and Ammann also agrees sufficiently herewith.

On the other hand, Joule[205] has long since shown that ordinary cast-iron is thermo-electrically negative towards copper, all the more, therefore, towards soft steel—a result which I should be inclined to predict from the quantity of combined carbon contained.

The minimum values of T. E. H. (obtained by cooling the red-hot bar as slowly as possible) of different kinds of steel[206] and of soft iron are approximately the same; whereas the maximum values of this constant (obtained by cooling the highly heated bar as rapidly as possible) differ enormously; this difference being a direct function of the quantity of carbon contained.

(*f*) *Thermo-electric effect of magnetization.*—Sir William Thomson[207] has shown that in a thermo element, consisting of magnetized and unmagnetized steel of the same hardness and form, thermo-currents due only to magnetic difference are generated. The direction of these currents was found to be in one case from unmagnetized to longitudinally magnetized through warm, in another from transversely magnetized to unmagnetized through warm, therefore also from transversely to longitudinally magnetized through warm.

For the purpose of informing myself of the magnitude of the thermo-electric difference thus produced, the following experiment was made: A soft rod (I, Table II) was tested for its electro-motive force when combined with copper (as described above, p. 348), and the locus of the

[205] Joule: Phil. Mag. (4), XV, pp. 538–'39, 1857.

[206] Steel is here used as distinguished from iron only by containing a greater proportion of carbon. No attention has been paid in this paper to the effects of P, S, Si, Mn, etc., so often present in both.

[207] Thomson: Phil. Trans. III, pp. 722–'7, 1856.

equation $E\tau = a\tau - \beta\tau^2$ constructed from *fifteen* very carefully made observations.

Hereupon a large magnetic battery, weighing 40 pounds, was so placed that each of the ends of the horseshoe touched a receiver. The distance between the poles of the magnet and the corresponding ends of the steel rod was thus about 50 millimeters. A second series of fifteen observations was now made. Upon comparing the locus of the latter with that that of the former, the two curves coincided so completely that no influence could be discerned.

Herefrom I conclude that the thermo-electric effect due to difference of magnetic state may, in comparison with that which can be produced by a difference of hardness, be completely neglected.

(*g*) *Relation between T. E. H. and density of steel.*—A very curious analogy was found in comparing the results at which Fromme[208] arrived, in studying the specific gravity of differently tempered steel, with the T. E. H. of similar rods as found in my experiments. Dr. Fromme, if I infer correctly, limited his experiments to rods whose diameter was greater than 2 millimeters, and less than 7 millimeters. His results are contained in the following table, the volume of the soft bar being put = unity.

TABLE IX.

| | Volume. | Volume-increase. | T. E. H. |
|---|---|---|---|
| Soft | 1.000 | 0.000 | 0.000 000 |
| Annealed blue | 1.002 | 0.002 | 0.000 024 |
| Annealed yellow | 1.005 | 0.005 | 0.000 042 |
| Glass-hard | 1.010 | 0.010 | 0.000 117 |

In the fourth column the T. E. H. of rods cited in Table III. (these, as I believe, corresponding very closely to those for which the data of Fromme apply) is added. If we take into consideration that the results were obtained from different material, the parallelism observable is striking. To the very large difference between glass-hard and yellow annealed, when compared with the much smaller difference between yellow and blue, blue and soft, as seen in both observations, I would once more call attention. The fact that glass hard rods can be considerably annealed at comparatively low tempeartures must be regarded as an adequate indication of their unnatural (strained) condition.

A second result of Fromme, that the specific gravity of thin rods suffers greater loss by glass-hardening than that of thick rods, also harmonizes with the conclusions drawn in § 7 (*b*) with reference to the T. E. H. of such rods.

[208] Fromme: Götting. Nachr. p. 165, 1876.

## 8.—HARDNESS AND SPECIFIC RESISTANCE OF STEEL: DEDUCTIONS.

From the data for the specific resistance of rods of different hardness inferences analogous to the above may be deduced.

(*a*) The specific resistance of steel increases continuously with its mechanical hardness.

(*b*) Rods like annealed differ but slightly, glass-hard rods considerably, with respect to their specific resistance.

(*c*) *Relation between the thermo-electric hardness and the specific resistance of steel.*—On comparing the values found for the ratio $\Delta S_0 / T.E.H.$, we infer that the specific resistance of steel is approximately a linear function of its thermo-electric hardness. In Fig. 30 these results are graphically represented.

I will remark, however, that the assumption of proportionality as based on the above figures is to be regarded as a first approximation

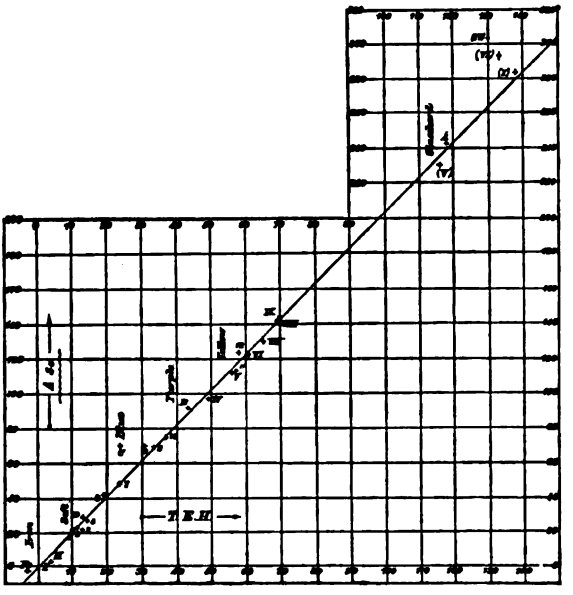

FIG. 30.—Relation between thermo-electric power and specific resistance.

only, notwithstanding the fact that the discrepancies fall within the errors of experiment. A rigid discussion of the latter comes more appropriately within the scope of another paper soon to appear. In this place I would only call attention to the following: In the thick bars

experimented upon the value of $\Delta S_0 / \text{T. E. H.}$ is usually too large; a fact which is easily accounted for, as the unavoidable resistances of contact above referred to will in this case have a relatively great effect, the resistances of the bars themselves being very small. In the rods included in Table VI it was impossible to secure uniform redness of ignition throughout; the ends invariably remained darker. As T. E. H. depends principally on the warm end, $\Delta S_0$, however, on the mean hardness of the whole bar, we have thus a second cause for an overlarge ratio.

So much I think to have fully established, that T. E. H. and specific resistance throughout their variations are very simple functions one of another. T. E. H. and specific resistance must therefore be looked upon as effects of the same cause, as *phenomena having some very intimate connection.*

(*d*) Particular attention must here be called to the remarkable result, that the specific resistance of steel can by a process of glass-hardening be increased to *nearly three times* its value in soft steel.[209] As this datum far exceeds that determined by Mousson (about 25 per cent.), it is not without some hesitation that I make it public. The care bestowed on the experiments, however, together with the regularity observed in the variation of the results, I believe sufficiently insure their correctness. See, moreover, § 6, E.[210]

(*e*) As deserving special notice, I will further add that the thermo-current always passes from the bar with greater to the bar with less resistance.[211] The few exceptions to this fact in the tables were afterwards found to be referable to errors of experiment by direct observation.

(*f*) Like T. E. H., so also the specific resistance of steel approximates to the value of this constant for soft iron. Upon the value found for

[209] It is to be observed, however, that the difference between the specific resistance of steel in the soft and hard states is dependent on the composition, increasing with the quality of carbon contained from a very small value in soft iron to the very large value above announced for steel.

[210] Chwolson reports the increase of resistance due to glass-hardening to be only 0.6 per cent. This I can only explain by supposing the results of this observer to have been obtained with wires suddenly cooled at a temperature below that referred to in § 7 (*c*).

[211] I would here again refer to the fact that, according to Magnus, Thomson, and Mousson, drawn-steel wire and hard-tempered steel are on opposite sides of soft steel, both with respect to their thermo-electric properties and their specific resistance. Thomson furthermore finds transversely magnetized steel electro-negative towards soft steel, this again towards longitudinally magnetized steel. Auerbach (Wied. Ann., V, p. 316, 1878), analogously, that the specific resistance of hard steel continuously increases as the rod passes from a condition of saturated longitudinal to a condition of saturated circular magnetization. The result above enunciated has therefore probably even a more general signification.

the ratio $\Delta S_0 / \text{T. E. H.}$, however, not much reliance can be placed, the factors involved being too small to admit of accurate determination.

With cast-iron no experiments were made.

## 9.—REMARKS ON THE ABOVE, CONSIDERED AS AUXILIARY TO THE DETERMINATION OF THE RELATION BETWEEN HARDNESS AND MAGNETIC MOMENT.

In this place I will avail myself of the experiments of Ruths on the relation between hardness and magnetic moment, these being perhaps the most comprehensive. With sufficient approximation for the purpose I will put the T. E. H. of glass-hard rods $= 120 : 10^6$; that of the yellow annealed, $= 40 : 10^6$; of the blue, $= 20 : 10^6$; and with these as abscissæ and Ruths' values for the corresponding permanent magnetic moments ("in millions of absolute units," milligrammes-millimeters-seconds) as ordinates, suppose the curves belonging to each of the bars to be constructed. These curves are given in figure 31, the attached number referring to the ratio between the length and the diameter of each rod.[212]

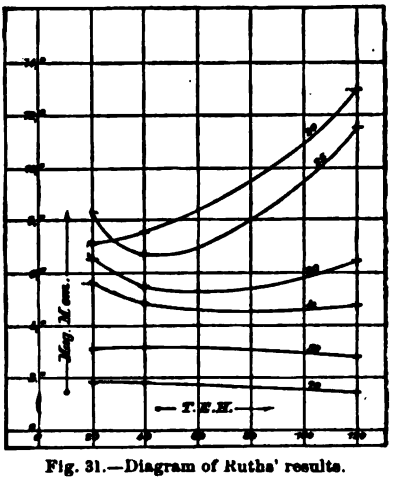

Fig. 31.—Diagram of Ruths' results.

I will omit the interesting deductions which Ruths makes from his data, these going beyond our present purpose.

From an inspection of the curves we derive the following important results, viz: that, like the electrical properties of steel and its specific gravity, so also the maximum of permanent magnetism is largely modified by the different degrees of glass-hardness of the bar (*i. e.*, those lying above yellow annealed, and scarcely distinguishable mechanically). In the second place, the results of Ruths, being obtained from comparatively thick rods, are largely influenced by structure. In view of these facts, I deem the hope by no means too sanguine that if, to avoid complications from structure, we experiment on thin rods, the maximum of permanent magnetism may be empirically expressed in terms of the dimensions and T. E. H. only; that, furthermore, from the parallelism discovered in the variation of specific gravity and the electrical prop-

[212] The data employed are those obtained by Ruths for rods 120 millimeters long, and 1.7, 2.4, 2.9, 3.8, 4.9, 5.9 millimeters, respectively, in diameter, with very powerful magnetizing forces.

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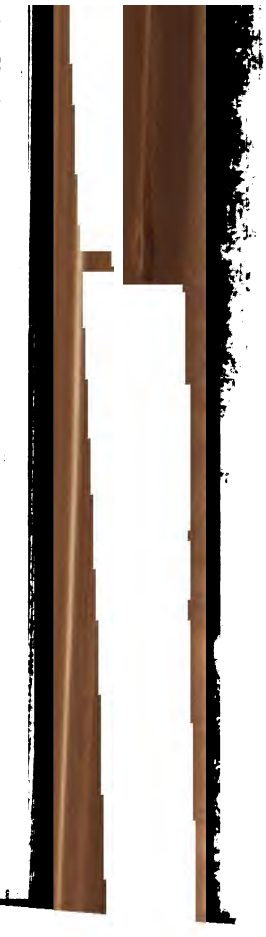
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